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PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-EIGHTH YEAR, 1899–1900.

BOSTON, April 12, 1900.

THE 539th regular meeting of the SOCIETY OF ARTS was held this day at 8 P.M., President Crafts presiding. Sixty persons were present. The report of the previous meeting was read and approved. Mr. Edward G. Thomas, '87, and Mr. Charles F. Tillinghast, '95, were elected to Associate Membership. The following paper was presented by title, "The Reflection of Light in the Neighborhood of the Critical Angle," by Mr. J. G. Coffin.

The President introduced Professor L. P. Kinnicutt, Director of the Chemical Department, Worcester Polytechnic Institute, who addressed the Society on "Recent Changes of Opinion in England in Favor of the Bacterial Purification of Sewage." The speaker defined the bacterial treatment of sewage as an "endeavor to obtain under control and supervision, results which are everywhere being produced in nature by agents which have been at work ever since life first appeared in the world. It is an attempt to carry on, under the best possible conditions, the processes of nature by which dead vegetable and animal matter is continually being changed into mineral substances."

The former idea that the higher plant life is capable of decomposing and purifying sewage has long been recognized as incorrect. The removal from sewage of putrifying substances is known to be due to certain minute plants called bacteria. The possibility of the purification of sewage by these agents, on a practical scale, was first demonstrated by the Massachusetts State Board of Health, as a result of the work of a number of eminent scientists, Drown, Sedgwick, Stearns, Hazen. The method suggested in their report is known as the Intermittent Filtration of Sewage.

A number of practical questions which remained unsolved in this report, led, in England, to an extensive investigation of the bacterial treatment of sewage, and has resulted in the study of the "open and closed septic tanks," and the development of the "single and double contact systems." The speaker explained these processes in detail, and also the results of extensive experiments which have been made in Manchester, England, during the last two years, on the best methods of sewage disposal. Persons interested in this subject should consult Professor Kinnicutt's paper, which is given in full in the February number of the Journal of the Association of Engineering Societies.

A discussion followed the reading of the paper. The thanks of the Society were tendered Professor Kinnicutt for his able and interesting address.

BOSTON, April 26, 1900.

The 540th regular meeting of the SOCIETY OF ARTS was held on this day in Room 22, Walker Building, at 8 P.M. Mr. George W. Blodgett presided. Two hundred and seventy persons were present.

The records of the previous meeting were approved. Mr. Hermann C. Lythgoe, Massachusetts Institute of Technology, '96, was elected to Associate Membership. On motion of Professor S. Homer Woodbridge, the chairman was empowered, in accordance with the By-Laws, to appoint a committee to nominate the Executive Committee for the ensuing year. The following gentlemen were appointed: Dr. Francis H. Williams, Professors A. Lawrence Rotch, George F. Swain, Edward F. Miller, and Mr. Arthur T. Hopkins.

After the announcement of the subject for the Annual Meeting,

Professor W. L. Puffer was introduced, and spoke on "Lecture Room Models for Illustrating the Modern Methods of Electric Transmission of Power." The paper was illustrated by means of working models, most of which were made by the engineer in the Electrical Engineering Laboratory of the Institute.

An electric motor, representing an engine or water wheel, drove by belts two exactly similar generators. These generators were so arranged that they could separately, or at the same time, supply a direct current or a *three*-phase alternating current.

The models were set up for this lecture to represent a great central station, supplying light and power to its immediate vicinity at 220 volts direct current using two-wire system. At the same time, the plant furnished, by means of three-phase system, current which passed out over a miniature transmission line to three transformers, arranged to operate a model twelve-phase induction motor. The latter was fitted with many types of armature.

Another part of the station output was raised to very high pressure by three step-up transformers, and transmitted over a long model pole line to a step-down transformer of relatively large size. This transformer was of peculiar construction, inasmuch as the magnetic circuits of the three phases, as well as the copper circuits, were interlinked in the same transformer. There were two secondaries, one of which was used for supplying three-phase power to a six-phase induction motor, which motor was supplied with various types of armatures and methods of connecting field windings. The other secondary supplied by one set of mains a local centre consisting entirely of incandescent lamps wired on that most beautiful of all systems, the three-phase, four-wire system. This model showed clearly the fine regulation of the system when working under the most severe conditions of unbalanced load.

The same transformer also supplied current to a rotary transformer of relatively large size which was used to supply the ordinary Edison three-wire system. The neutral wire was obtained from the electrical centre of the transformer coil.

Another branch of the high potential mains was carried to a centre of distribution at which there were three series of miniature incandescent lamps taking power directly from these mains. Three transformers, with both primary and secondary circuits controlled by double throw-switches, were arranged to show the possibilities of

change of voltage by the various well-known electrical methods of connecting the three-phase circuits. These same transformers could be used to change the three-phase system into two-phase systems, on which were shown both incandescent lamps and a one-fourth-phase induction motor.

The lecture was most thoroughly enjoyed by the large audience present, which concurred most heartily in the vote of thanks tendered Professor Puffer.

BOSTON, May 10, 1900.

The 38th Annual Meeting, 541st regular meeting, of the SOCIETY OF ARTS was held in the Rogers Building, on this day at 8 P.M. President Crafts presided. Forty-five persons were present.

The records of the previous meeting were read and approved. It was voted that the Annual Report of the Executive Committee, read by the Secretary, be accepted.

ANNUAL REPORT OF EXECUTIVE COMMITTEE.

The first meeting of the SOCIETY OF ARTS for the present year was held on October 12, 1899. Fourteen meetings have been held, the average attendance being ninety persons. The following papers have been read:

"Some Practical Applications of Storage Batteries," by Mr. T. S. Woodbridge.

"Visual Signals," by Mr. H. C. Spaulding.

"Use of Kites to Obtain Meteorological Data," by Professor A. Lawrence Rotch.

"New Cellulose Industries," by Mr. A. D. Little.

"Exhibition of Building Stones and Minerals collected by the Geological Department of the Massachusetts Institute of Technology, in Association with the Commissioners of Massachusetts and the United States for the Paris Exposition," by Professors Niles and Crosby, and Mr. Fuller.

"The Character and Extent of Food and Drug Adulterations in Massachusetts, and the Systems of Inspection of the State Board of Health," by Mr. Albert E. Leach.

"A New Dynamo-static Machine," by Professor Elihu Thomson.

"An Architect's Tour through the Riviera and Central France," by Professor E. B. Homer.

"Massachusetts Roads, Old and New," by Mr. William E. McClintock.

"Water Storage on the Gila River, Arizona," by Mr. F. H. Newell.

"The Boston Elevated Railway System," by General W. A. Bancroft.

"Recent Changes of Opinion in England in Favor of the Bacterial Purification of Sewage," by Professor L. P. Kinnicutt.

"Lecture Room Models for Illustrating the Modern Methods for Electric Transmission of Power," by Professor W. L. Puffer.

"Steel, Gray, and Gun Iron Castings; their Uses and Relative Values," by Mr. W W. Bird.

At the first meeting of the year, the resignation of the Secretary, Mr. Arthur T. Hopkins, was accepted, and Dr. Wendell elected to the position. Mr. Hopkins's administration had been most successful, and the Society regretted that his removal from Boston prevented his continuation in office.

During the year there have been a number of changes in membership. Mr. William Jackson, City Engineer of Boston, has been elected to Life Membership, making the number of such members 47. Of the Associate Members, 2 have died, 8 resigned; 22 have, however, been elected, making the present membership 339.

In the death of Professor Silas W. Holman, the Society lost one of its most distinguished members, and the Institute of Technology one of its most eminent teachers. While his health lasted he evinced a most active interest in the welfare of the Society, as its Secretary from 1881–1883, and by his many contributions to the *Quarterly*. A sketch of his life will be found in the *Technology Review* for July, 1900.

The publication of the *Technology Quarterly* has been continued under the same management as last year. Since the last annual report, twenty papers have been published in the *Quarterly*, of which six were read before the Society, the rest being presented only by title. Besides these, the Proceedings of the Society and the Review of American Chemical Research, contributed by members of the Chemical Department, have appeared regularly. Mr. Axson's article on "Nitrites as a Product of Combustion," is the first of a new series of contributions from the Laboratory of Sanitary Chemistry. Two of the articles embody the results of notable pieces of work done by members of the Faculty. One of these is an article on the "Geological History of the Nashua Valley during the Tertiary and Quaternary Periods," by Professor W. O. Crosby, in which we have the scientific results of an extended investigation carried on under the auspices of the Metropolitan Water Commission. The other is by Professor Hofman, on "The Temperatures at which Certain Ferrous and Calcic Silicates are Formed in Fusion, and the Effect upon These Temperatures of the Presence of Certain Metallic Oxides," a subject of great practical importance in Metallurgy. The research was carried on under a grant from the C. M. Warren Fund of the American Academy of Arts and Sciences.

The Secretary read a communication from the Committee on Nominations, in which the following gentlemen were named as candidates for the Executive Committee for the year 1900–1901: George W. Blodgett, Desmond FitzGerald, Edmund H. Hewins, Charles T. Main, and James P. Munroe. Mr. Blodgett announced that the Executive Committee had voted to nominate George V. Wendell to be candidate for the office of Secretary. The President appointed Dr. Robert P. Bigelow to distribute and count the ballots. The vote resulted in the election of the above-named candidates.

The following papers were presented by title:

"Outlines of the Geology of Long Island and its Relation to the Public Water Supplies," by Professor W. O. Crosby.

"Notes on the Geology of the Sites of the Proposed Dams in the Valleys of the Housatonic and Ten-Mile Rivers," by Professor W. O. Crosby.

"Tests of Fire Retardent Material," by Charles L. Norton.

After the business was transacted, Mr. W. W. Bird, of the Broadway Iron Foundry, Cambridge, was introduced, and gave an interesting paper on "Steel, Gray, and Gun Iron Castings; their Uses and Relative Values." This paper is printed in full in the Junior Proceedings of the American Society of Mechanical Engineers. During the discussion which followed, Dr. Henry O. Marcy referred to the valuable work which has been done by Nathaniel Washburn, on manganese iron. The thanks of the Society were extended to Mr. Bird.

GEORGE V. WENDELL, *Secretary.*

THE ECLIPSE EXPEDITION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY TO WASHINGTON, GEORGIA.

Part I. Introduction.

By ALFRED E. BURTON.

The total solar eclipse of May 28th, 1900, was the first since 1869 to be visible at points near our Atlantic coast. Students of astronomy in the Eastern States very generally availed themselves of this opportunity to witness the wonderful phenomena of totality. Eclipse expeditions were by no means confined to the larger observatories. The colleges generally sent parties to different points along the track of the shadow.

The corporation of the Massachusetts Institute of Technology made an appropriation in the fall of 1899 to send a small party south to make "Time observations in connection with the eclipse." The new geodetic observatory of the civil engineering department was to furnish the instruments, and the instructors in the geodetic option were to be the observers. The party was placed in charge of the writer. Professor Arthur G. Robbins and Mr. G. L. Hosmer were, at first, the only other members, but later we were able to increase the size of the party and to extend somewhat the scope of the work. Professor Dana P. Bartlett, Mr. Walter Humphreys and Mr. Harrison W. Smith, all from the Institute, volunteered their services, and the program was made to include magnetic observations and the photographing and sketching of the corona.

The geodetic observatory furnished an astronomical transit with latitude level, a chronometer and a chronograph, also a magnetometer and dip circle. Two equatorially mounted telescopes, one of five inches and one of three inches aperture, were hired from the firm of Alvan Clark & Sons of Cambridge. These telescopes were fitted with eye-pieces and shades especially for eclipse work.

The above named apparatus, together with a few surveying instruments and a special form of camera devised by Mr. H. W. Smith for photographing the corona, made up our outfit. We did not attempt any new line of research. It was new work for all and it did not seem wise to try too many things.

The point to be occupied as an observing station was chosen as early as November, 1899. The selection was made after a careful examination of the largest scale maps to be obtained, on which the path of the moon's shadow was plotted. Washington, Georgia, was one of the points of highest altitude to be found on the central line of the shadow and was directly accessible by rail. It was not a point mentioned by Professor Frank H. Bigelow in his report on the meteorological conditions prevailing for the past three years along the path of totality, but, as it was in a region shown by his diagrams to be favorably located with reference to probable cloudiness, we decided to make it our station. Events afterwards showed that our choice had been a wise one and fortunate in many ways not to be anticipated. The town itself was interesting and the people most hospitable and appreciative of our work. The success and pleasure of the trip was due in no small measure to our happy location.

Professor W. H. Pickering of Harvard Observatory, Mr. A. Lawrence Rotch of Blue Hill Observatory, and Mr. A. E. Douglass of the Flagstaff Arizona Observatory decided to come to this point also. This arrangement was mutually beneficial and it made our time observations of greater practical utility.

The writer left Boston May 9th on the Savannah steamer which carried the outfits for all the different parties. From Savannah the instruments were taken by rail to Washington, Georgia, arriving without any mishap.

Mr. J. Rayner Edmands of Harvard Observatory had been South in April and had picked out a favorable site for the telescopes and cameras. The erection of the brick and cement pier for the astronomical transit and the building of the protecting sheds were begun at once, and a few days later, when Mr. Hosmer arrived, all was ready for the latitude and longitude observations. The maps of this vicinity are not exact and are not controlled by triangulation, therefore the latitude and longitude as scaled from the map was not deemed reliable, and our first work was the

determination of our geographical position. From maps the latitude of Washington was found to be N. 33° 40′ and the longitude W. 82° 42′, or five hours, thirty minutes and forty-eight seconds. By direct observation, using Talcott's method for latitude and a telegraphic time signal from Washington, D. C., for longitude, the position of the station was found to be in latitude N. 33° 43′ 49″ and longitude W. five hours, thirty minutes and fifty-six and two-tenths seconds. This determination of our position placed us some four miles north and nearly two miles west of our map location and off the central line sufficiently to reduce the period of computed totality about two seconds.

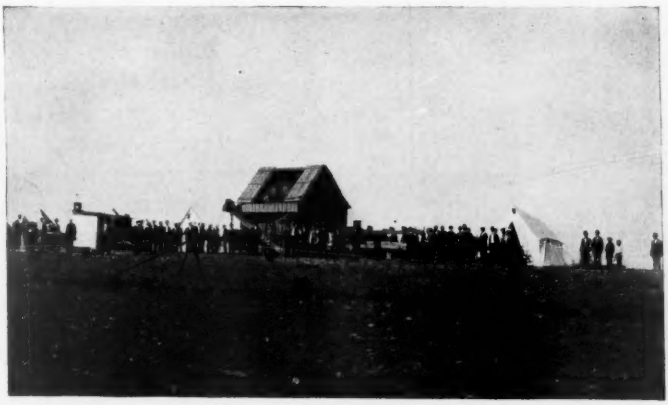


FIG. 1. — GENERAL VIEW OF ECLIPSE STATION.

The next step in our work was to mark the meridian line permanently, and make determinations of the magnetic declination and dip.

Finally the plan was drawn showing the position of the transit pier and the magnetic station with reference to the nearest building and road, and we were ready for the eclipse. Professors Robbins and Bartlett and Messrs. Humphreys and Smith arrived in Washington May 26th.

The assignments for the different members of our party were as follows. To Mr. George L. Hosmer was given the position of chief observer, his excellent work during the past two years at the geodetic observatory having shown him to be especially well quali-

fied for this work. On the day of the eclipse he was to use the five-inch equatorial and record the four contacts on the chronograph.

To Professor Arthur G. Robbins was assigned the observation of the first and fourth contact, using the three-inch equatorial and a stop-watch, and he was also to count aloud seconds during totality as marked by the beats of the metronome.

To Professor Dana P. Bartlett was assigned the observations with the magnetometer on the morning of the eclipse. All these gentlemen have made full reports of their work, which are printed in the later pages of this article. No further mention need be made here of these observations except to say that they were carried out in a most satisfactory manner.

FIG. 2. — SMITH'S CAMERA.

Mr. Harrison W. Smith constructed a special form of camera with a very ingenious arrangement for following the motion of the sun. With this camera six photographs of the corona were made during the eighty-six seconds of totality. The time of the exposure varied from one-half a second to twenty seconds. All the plates came out well, and a photogravure made from an enlargement of the one of ten seconds' exposure is printed as a frontispiece to this number of the *Quarterly*. A picture of the camera and a description by Mr. Smith of its construction are given here.

The camera with which the photographs of the corona were taken consisted of a wooden box, with the reversible back of an ordinary 4 x 5 camera attached at one end and the lens at the other. The lens was borrowed from a small telescope, and had an aperture of three inches and focal length of forty-three inches. In order to make the long exposure, it was necessary to provide some means of following the motion of the sun; and this was accomplished by mounting the lens end of the camera on hinges and supporting the other end on

a tangent screw. The base of the camera was securely mounted on posts, as shown in the photograph, being tilted so that the plane of motion of the camera about the hinged end should be parallel to the plane of the earth's equator. The tangent screw was operated through a series of gear-wheels, by means of a small crank, shown in the photograph at the lower end of the base of the camera. The ratio of the gear and the pitch of the tangent screw were such that one-half a revolution of the crank would cause the camera to rotate through an angle of fifteen seconds. Consequently, by rotating the crank at the rate of one-half revolution each second, the desired result was obtained. It was found that, by following the beats of the metronome pendulum or listening to the counter, the driving could be made sufficiently uniform by hand. The plate was protected from reflection from the inside of the camera box by means of a series of screens distributed along the inside.

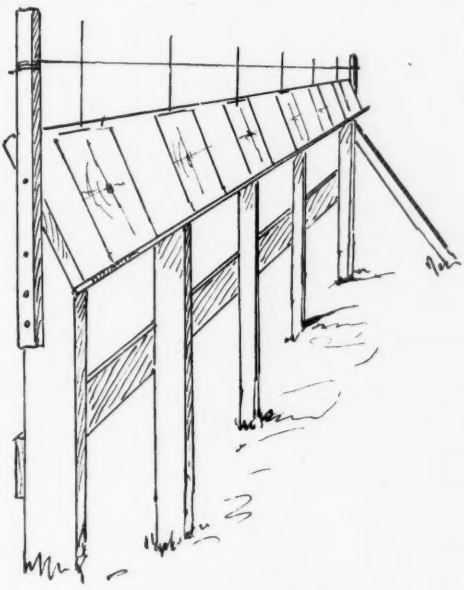


FIG. 3. — THE SKETCHING STAND.

The writer while arranging the program for the eclipse party became interested in developing a scheme for sketching the corona, which, although not containing anything especially novel, may be of some interest. In this work he was ably assisted by Mr. Walter Humphreys. Sketching the corona now occupies a rather despised position in the minds of astronomers, but it seems to the writer that it still serves a useful purpose and should not be abandoned. Photography fails to give the impression the corona makes on the naked eye. At Washington, Georgia, we made an attempt to systematize the drawing so as to utilize fully every second of time. A sketching stand, Figure 3, was erected of such a height that by standing in front of it one could look from the sun to the drawing with the least movement of the head and the eye. On this stand was tacked a sheet of paper already supplied with a black disc to represent the moon, together with vertical and horizontal lines and concentric circles to aid in judging directions and distances. Above the upper edge of the board was stretched a horizontal wire; in front of each sketcher this wire was crossed by a vertical one,

and these wires were of the greatest assistance in determining the directions of the coronal streamers and in defining the quadrants to be drawn. We were fortunate in finding in Washington a number of ladies who were skilled in drawing and willing to practice conscientiously in preparation for the work. The practice consisted in drawing from various diagrams of coronas held up on the end of a pole so as to appear at about the proper angular elevation of the sun. The time of sketching was regulated by calling out the seconds to the number of eighty-five, just as was to be done on the day of the eclipse. To each of the ladies was assigned the drawing of a single quadrant. Mr. Humphreys and the writer attempted the whole corona. The results of our work are shown in the accompanying illustration, Figure 5. The small diagrams are very much reduced copies of the sketches made during totality. The large diagram at the top of the page is taken from a pastel drawing finished by the writer twenty-four minutes after totality and is both a composite and a memory sketch. Very little color was apparent to the eye in the coronal light, so that black and white give a fair representation of the effect. The eyes of all the sketchers were closed five minutes before totality and only opened after the counting of the seconds began.

FIG. 4. — SKETCHING CLASS.

A reproduction of the plan showing the location of the instruments is here given. Such a plan is useful should it be desired to occupy again the magnetic station to note changes in declination and dip.

A diagram, Figure 7, is given to show the relation of the points of first and fourth contact to the vertical. A second diagram, Figure 8, shows the approximate relation of the rays of the corona to the axis and equator of the sun. This diagram is constructed from an enlargement of the photograph of ten seconds' exposure.

In conclusion, the writer wishes to acknowledge his indebtedness to the Harvard, Blue Hill and Flagstaff Observatories for aid and co-operation. To the people of the city of Washington, Georgia, all feel their indebtedness for a most pleasant experience of real Southern hospitality.

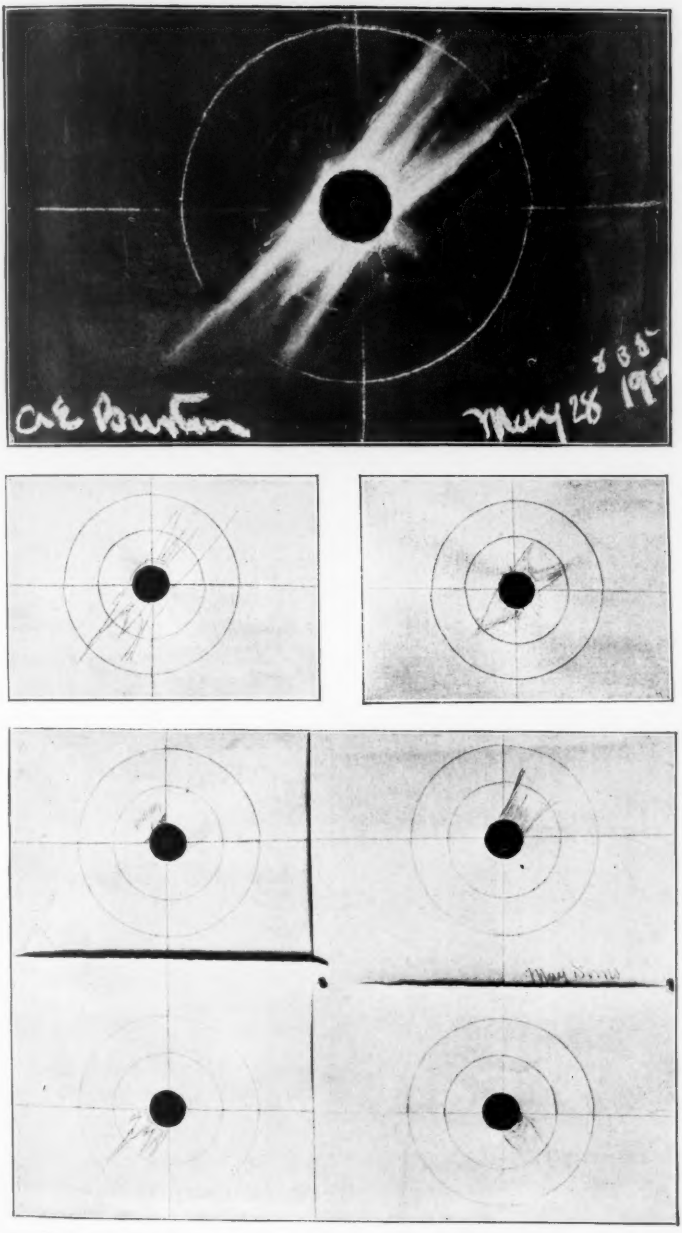


FIG. 5.—COMPOSITE SKETCH AND SKETCHES MADE DURING TOTALITY.

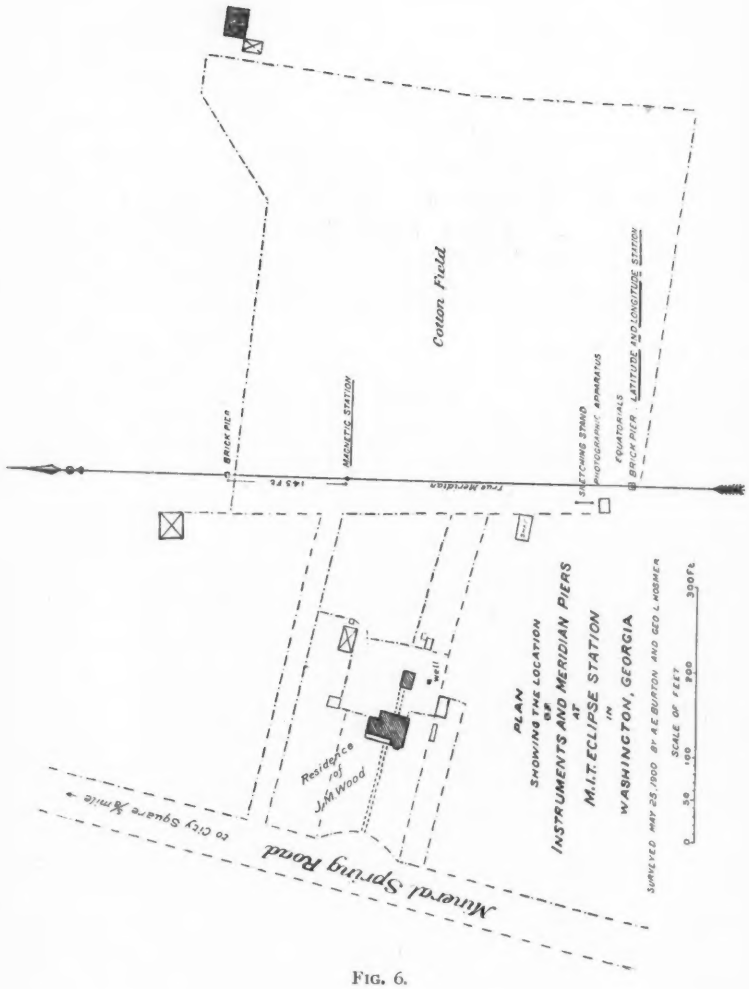

Cotton Field
BRICK PIER
MAGNETIC STATION
1457 ft.
True Meridian
SKETCHING STAND
PHOTOGRAPHIC APPARATUS
EQUATORIALS
BRICK PIER
LATITUDE AND LONGITUDE STATION
Well
Residence of J.M. Wood
Mineral Spring Road
to City Square ¼ mile
PLAN
SHOWING THE LOCATION OF
INSTRUMENTS AND MERIDIAN PIERS
AT
M.I.T. ECLIPSE STATION
IN
WASHINGTON, GEORGIA
SURVEYED MAY 25, 1900 BY A.E. BURTON AND GEO. L. ROBNER
SCALE OF FEET
0 50 100 200 300 ft.

FIG. 6.

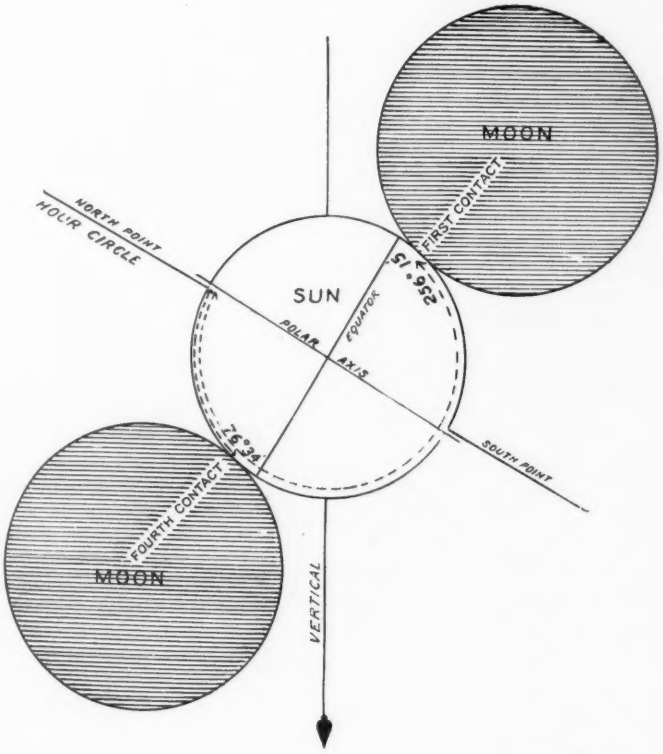


FIG. 7. — DIAGRAM SHOWING POSITIONS OF POINTS OF FIRST AND FOURTH CONTACTS.

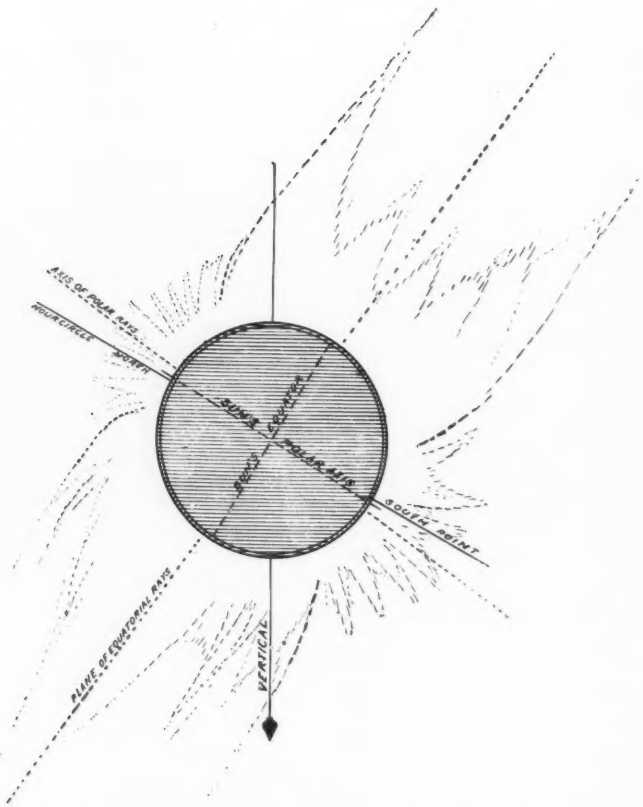


FIG. 8. — DIAGRAM SHOWING THE RELATION OF THE RAYS OF THE CORONA AND THE SUN'S AXIS.

Part II. Report of Observations.

By GEORGE L. HOSMER.

The part of the work assigned to me by Professor Burton included the following observations: the determination of the position of the station, correction and rating of the chronometers, observation of the magnetic declination and dip, and observation of the four contacts of the eclipse.

The instruments with which the latitude and longitude were to be determined were: a two and one-half inch portable transit, carrying a micrometer and a level for latitude work, one solar and two sidereal chronometers, a chronograph, a switch-board and other smaller apparatus The place selected for the transit station was on slightly elevated ground, with a clear meridian and a good view toward the east. A brick pier was built for the transit and a rough shed eight feet square built over it. At the earliest possible moment the transit was mounted and adjusted into the meridian, and the work of finding the corrections and rates of the chronometers was begun. Time observations were made as often as possible, sidereal chronometer No. 541, in circuit with the chronograph, being used as the principal chronometer. The correction to the solar chronometer (No. 528) was obtained by making comparisons at coincident beats of the two chronometers. Observations for latitude by Talcott's method were made successfully on but one night. This instrument will hardly admit of very accurate work as the reversal is difficult, but the results are probably as accurate as are needed in this case. Soon after the completion of the building a telephone was put in, which allowed the observatory to be connected with the telegraph office. It was found that by placing the transmitter of the office telephone near the sounder the ticks could be heard by an observer at the transit station. It was also found that this office received a time signal at 12 M. (75th meridian time) each day directly from Washington, D. C. Thus by holding the chronograph key in one hand and the telephone receiver to his ear with

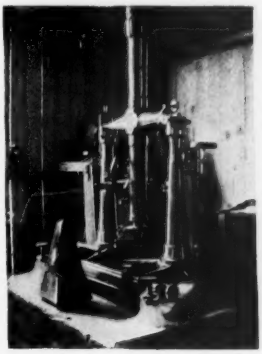


Fig. 9. — Astronomical Transit.

the other, an observer could record on his chronograph the instant of 12 o'clock Eastern standard time. This method was used in determining the longitude of the station. Of course the full personal equation of the observer enters into this observation, still the arrangement was better than was expected when the expedition was planned, and the accordance of results indicates that the accuracy is nearly as high as that of the latitude observations.

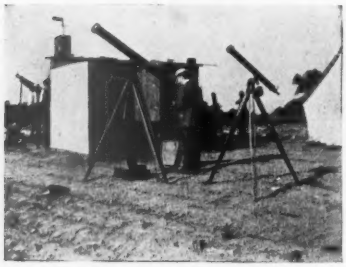


FIG. 10. — EQUATORIALS.

Whenever time could be spared from the work of preparing for the eclipse itself, the magnetic declination and dip were observed. The magnetometer used was of the Kew pattern. The magnet was suspended by three or four silk fibres after the torsion had been removed. All iron or steel was carried to a distance of at least 100 feet from the instrument before beginning operations. After the transit had been closely brought into the meridian a small brick pier was built due north from the first one, and a point was marked upon it bearing exactly north from the central point of the transit pier. Between the two and on the line a point was set for the magnetic station. A target was set exactly in line on the north side of the transit shed to use in taking readings with the magnetometer. Thus the angle between the axis of the magnet and the true meridian could be read directly. The axis of the magnet was determined by scale readings in the direct and inverted positions. The magnetic observations were of secondary importance in the work undertaken by the party, so that little time was given to them; the observations are therefore incomplete and not very well checked.

FIG. 11. — MAGNETOMETER.

The observations of the four contacts between the sun and moon were to be observed with the five-inch equatorial and to be recorded on the chronograph. The telescope was therefore set up

quite close to and just northeast of the transit shed. The wire leading from the chronograph to the observing key was passed out through the north opening of the shed. Through this opening the face of the chronometer and the chronograph could be watched without leaving the telescope. A second chronometer, keeping local mean time, was placed on the ground underneath the five-inch equatorial to be used by all observers as a finder. The program of observation was simply to record the times of the four contacts and at the second contact to call "tip" as a signal for Professor Robbins to begin counting seconds. The conditions were all very favorable at the time of the eclipse and this program was carried out successfully. The transit of the moon's limb over a solar spot was also observed by means of a stop-watch. Following are the results of all of the observations, with specimens of the records and computations.

RECORD OF A LATITUDE OBSERVATION ON MAY 26TH.

LATITUDE RECORD.

Station, Washington, Ga. Instrument, Temple No. 1. Date, May 26, 1900. Observer, G. L. H.

Star.	Mag.	Z. D.	N. or S.	Chr. Time Transit.	Microm. Turns.	Level. N.	Level. S.	Remarks.
				h. m				
2125	6.3	5° 11′	S	13 37	16.063	83.0	30.0	Eye-piece toward micrometer.
2141	5.8	5° 15′	N	13 43	13 504	31.0	83.5	Level "O" opposite eye-piece.

$t = 2.559.$

$\frac{1}{2}(\delta + \delta')$	33° 47′ 09″.3	log t. = 0.40807		
$\frac{1}{2}(m - m')$	3′ 19″.3	log r. = 2.19257	114.5	N
	33° 43′ 50″.0	2.60064	113.0	S
Lev. corr.	— 0″.4	2 0.30103	4) + 1.5	
	33° 43′ 49″.6	2.29961	+ 0″.4	
Refrac.	— 0″.05	199″.3		
	33° 43′ 49″.55			

COMPUTATION OF THE APPARENT DECLINATION OF STAR NO. 2125.

Formulæ $\begin{cases} [p + \frac{\Delta p}{200}(t - t_0) + \mu](t - t_0). \\ \delta = \delta_0 + \tau\mu + g\cos(G + \alpha_0) + h\cos(H + \alpha_0)\sin\delta_0 + i\cos\delta_0. \end{cases}$

From Greenwich 10-yr. Catalogue, 1880, No. 2125, N. P. D. = 61° 19′ 36″.98.

$p = +18''.352 \times 20 = 367''.040.$ $\Delta p = -.171 \times .10 \times 20 = -0''.034.$

N. P. D. 1880 =	61° 19′ 36″.98	367″.04
Change 20-yr.	6′ 07″.01	.03
N. P. D. 1900	61° 25′ 43″.99	367″.01
δ 1900	28° 34′ 16″.01	

$\delta o = 13h.\ 36m.\ 07s.$
$= 204° 02'$
$G = 12° 34'$
$H = 203° 39'$
$G + \delta o = 216° 36'$
$H + \delta o = 47° 41'$
$\log g = +1.1598$
" $h = +1.3046$
" $i = -0.547$
$i = -3''.52$

g 1.1598
cos (6 + δo) 9.9046
1.0644
$-11''.60$

i -0.547
cos δo 9.944
-0.491
$-3''.10$

h $= +1.3046$
cos (H + δo) + 9.8282
sin δo + 9.6795
+ 0.8123
$+6''.491$
$\delta o = 28° 34' 16''.01$
$-11''.60$
$+6''.49$
$-3''.10$
$\delta = 28° 34' 09''.80$

May 26, 1900.

Results of Latitude Observations.

Pair. (Gr. 10 W. Lat.)	Latitude.
2125 / 2141	33° 43′ 49″.6
2200 / 2211	33° 43′ 48″.3
Mean	33° 43′ 48″.95

Results of Longitude Observations.

Date.	Chronometer.	Longitude.[1] h. m. s.
May 26	No. 528	5 30 56.3
May 27	No. 541	5 30 56 1
	Mean,	5 30 56 2

[1] The latitude and longitude as taken from the U. S. G. S. map are $\phi = 33° 40'$; $\lambda = 82° 42'. = 5h.\ 30m.\ 48s.$

Table of Chronometer Corrections and Rates.

Date. May	Hour. Sid. or Mean.	Corr. No. 541.	Corr. No. 528.	Rate (hour).[1] No. 541.	Rate (hour).[1] No. 528.
	h. m.	s.			
21	13 30 (s)	−33 8	.....	.....	.....
		s.			
21	5 51 P.M. (m)	.....	−27.95	.....	.....
22	9 00 P.M. (m)	.....	−28.48	.....	.....
24	12 50 (s)	−31.96	.....	+.0257	.....
26	7 40 A.M. (m)	.....	−28.45	.....	.....
27	12 15 (s)	−30.56	.....	+.0195	+.011
28	11 25 A.M. (m)	.....	−27.89	.....	.....

[1] Third chronometer not used.

FORM 1. — TRANSIT RECORD FOR TIME.

Station, Washington, Ga. Date, May 24, 1900. Observer, G. L. H. Chronometer, Bond (Sid.) 541.

20 Comae. E		8 Can. Ven. E	76 Urs. Maj. E			43 Comae. W		ξ Urs. Maj. pr. W			
26.0	15.0	32.0	34.0	09.0	+34.0	26.0	18.0	32.0	+36.0	37.0	09.5
31.0	10.0	36.0	27.0	16.0	.01	34.0	10.0	40.0	.01	29.5	17.0
57.0	25.0	63.0	61.0	25.0	+.34	60.0	28.0	72.0	+.36	66.5	26.5
25.0		+34.0	25.0			28.0		+36.0		26.5	
32.0			36.0			32.0				40.0	
		b e = +.34						b w = +.36			
h.	*m.*	*s.*									
12	24	49.12	29	00.32		36	51.16	07 19.05	19	45.65	
	25	02.55		16.90		37	18.60	32.90	20	07.65	
		16.00		33.64		missed		47.05		29.20	
		29.20		50.37		38	13.70	08 01.40		50.70	
		42.43	30	07.02		38	41.10	15.40	21	13.00	
12	25	15.87	29	33.65		37	46.14	07 47.16	20	29.24	
Bb		+.36		+.45			+.65	+.42		+.59	
K(negl.)											
t, 12	25	16.23		34 10			46.79	47.58		29.83	
δ 12	24	44.73		02.49			15.00	15.36		57.06	
		−31.50		−31.61			−31.79	−32.22		−32.77	

FORM 2. — COMPUTATION OF COLLIMATION AND AZIMUTH CONSTANTS.

COMPUTATION OF △ T FOR OBSERVATIONS ON P. 38, BOOK 12.

	Star.	Pos.	$\alpha - t$,	C	A	Cc	Aa	$\alpha - t, -Cc - Aa$	v	
	20 Comae	E	−31.50	−1.06	.22	.29	.09	−31.88	.08	
	8 Can. Ven.	E	−31.61	−1.35	.19	.36	.07	−32.04	.08	
	76 Urs. Maj.	E	−31.79	−2.24	−1.10	.61	−.43	−31.97	.01	△ T = −31.96
	43 Comae	W	−32.22	1.13	.10	−.31	.05	−31.96	.00	May 24th. at 12h. 50m.
	ξ Urs. Maj. pr.	W	−32.77	1.79	−.66	−.48	−.33	−31.96	.00	
			$\alpha - t$,	C	A	Cc	$\alpha - t, -Cc$	Aa	$\alpha - t, -Cc - Aa$	c = −.33
1st approx.	Mean of time stars	E	−31.56	−1.20	.20	.40	−31.96	.08	−32.04	ae = +.44
	Azimuth star	E	−31.79	−2.24	−1.10	.74	−32.53	−.44	−32.09	
	Mean of time stars	W	−32.22	+1.13	.10	−.37	−31.85	.04	−31.89	aw = +.44
	Azimuth star	W	−32.77	+1.79	−.66	−.59	−32.18	−.27	−31.91	
2d approx.	Mean of time stars	E	....	....	....	.32	−31.88	.08	−31.96	c = −.27
	Azimuth star	E	....	....	....	.60	−32.39	−.43	−31.96	ae = +.39
	Mean of time stars	W	....	....	....	−.31	−31.91	.05	−31.96	aw = +.50
	Azimuth star	W	....	....	....	−.48	−32.29	−.33	−31.96	

MAGNETIC OBSERVATIONS.

DECLINATION.

May 24, 1900. Scale reading of axis = 41.5

Circle reading on axis at 11*h*. 10*m*. A.M., local time	A	193° 07′ 20″
	B	05′ 40″
	Mean	193° 06′ 30″
Circle reading on Meridian mark . . .	A	192° 03′ 40″
	B	02′ 00″
	Mean	192° 02′ 50″

Declination at 11*h*. 10*m*. A.M., 1° 03′ 40″ East.

Circle reading on axis at 2*h*. 30*m*. P.M. . .	A	307° 11′ 00″
	B	11′ 40″
	Mean	307° 11′ 20″
Circle reading on Meridian mark . . .	A	306° 59′ 40″
	B	00′ 00″
	Mean	306° 59′ 50″

Declination at 2*h*. 30*m*. P.M., 1° 11′ 30″ East.

Circle reading on axis at 4*h*. 00*m*. P.M. . .	A	307° 11′ 00″
	B	11′ 40″
	Mean	307° 11′ 20″
Circle reading on Meridian mark . . .	A	306° 59′ 40″
	B	00′ 00″
	Mean	306° 59′ 50″

Declination at 4*h*. 00*m*. P.M., 1° 11′ 30″ East.

DIP.

May 23, 1900, at 5*h*. 45*m*. P.M., local time.

Needle No. 2.

Polarity of A end south.

	Circle East.		Circle West.	
	Face East.	Face West.	Face East.	Face West.
S	63° 49′ 48′	63° 17′ 16′	65° 16′ 15′	63° 51′ 51′
N	63° 53′ 51′	63° 23′ 22′	65° 03′ 04′	63° 38′ 38′
	63° 50′.2	63° 19′.5	65° 09′.5	63° 44′.5

Mean Circle E = 63° 34′.8. Mean Circle W = 64° 27′.0.

Mean 64° 00′.9.

Polarity A end north.

	Circle East.		Circle West.	
	Face East.	Face West.	Face East.	Face West.
S	64° 38′ 39′	64° 10′ 09′	64° 09′ 10′	64° 53′ 53′
N	64° 43′ 44′	64° 15′ 14′	64° 26′ 27′	64° 41′ 41′
	64° 41′.0	64° 12′.0	64° 18′.0	64° 46′.8

Mean Circle E = 64° 53′.0. Mean Circle W = 64° 32′.4.

Mean 64° 42′.7.

Resulting Dip 64° 21′.8.

CONTACT OBSERVATIONS.

	I.	II.	III.	IV.
	h. m. s.	*h. m. s.*	*h. m. s.*	*h. m. s.*
No. 541,[1] . . .	23 25 15 5	0 32 55.9	0 34 22.3	1 51 43 7
Corr. to No. 541,	30 35	30 33	30.33	30.31
	23 24 45.15	0 32 25 57	0 33 51 97	1 51 13.39
O's R. A. . . .	4 19 14.79	4 19 14.79	4 19 14.79	4 19 14.79
	19 05 30.36	20 13 10.76	20 14 37.18	21 31 58.60
Red. (— 12*h.*) . .	3 07.66	3 18.75	3 18 98	3 31.66
Local time . . .	7 02 22.7(0)[2]	8 09 52 0(1)	8 11 18.2(0)	9 28 26.9(4)

[1] Read from chronograph sheet.

[2] Estimated to be 2*s.* late.

NOTES.—Third contact was not as distinct as second.

Moon's limb bisected large spot at 7*h.* 24*m.* 12.1*s.*

PART III. REPORT OF OBSERVATIONS.

BY ARTHUR G. ROBBINS.

The work assigned to me in observing the total eclipse of the sun at Washington, Ga., May 28, 1900, was to obtain the time of the first and of the last contact, using a telescope and stop-watch, and, during totality, to count aloud the beats of a metronome for the benefit of those engaged in taking photographs and of those who made sketches of the corona. In addition, I made a naked-eye observation of the time of the second and of the third contact, using two stop-watches. The telescope used was a three-inch equatorial, magnifying thirty-two diameters.

At 6h. 58m. 30s. A. M., about four minutes before the time of first contact, I started the stop-watch on the tick of the chronometer and began observing that part of the sun's limb where the contact was to take place. Suddenly the limb of the sun became finely serrated along a small arc. This was quickly followed by a slight flattening and then I pressed the spring of the stop-watch. The interval of time between suspicion and conviction was, I think, less than half a second.

	h. m. s.	
Started stop-watch at . . .	6 58 30.0	chronometer time.
Stopped " " . . .	4 14.3	
	7 02 44.3	
	27 9	chronometer fast.
Local mean time of first contact,	7 02 16.4	

At 8h. 7m., about three minutes before totality, I started simultaneously two stop-watches on the tick of the chronometer, put on a pair of dark glasses, started the metronome and placed one of the watches beside it on a box.

The sun now showed as a very narrow crescent of light; this rapidly shortened to a point and disappeared. Then I pressed the spring of the stop-watch, and, at a pre-arranged signal from Mr. Hosmer, began calling aloud the beats of the metronome and continued so calling till several seconds after totality had ceased. Between sixty and seventy seconds after the beginning of totality, I exchanged stop-watches and began to look for the first beam of sunlight. When this flashed into view I pressed the spring of the second stop-watch.

	h.	*m.*	*s.*	
Started stop-watches No. 6 and No. 8 at	8	07	00.0	chronometer time.
Stopped stop-watch No. 6 at		3	21.0	
	8	10	21.0	
			27.9	chronometer fast.
Local mean time of second contact .	8	09	53.1	
Stopped stop-watch No. 8 at		4	46.3	
	8	07	00.0	
	8	11	46.3	
			27.9	chronometer fast.
Local mean time of third contact . .	8	11	18.4	

The method of observing the fourth contact was similar to that followed in observing the first contact.

	h.	*m.*	*s.*	
Started stop-watch at	9	24	30.0	chronometer time.
Stopped " "		4	14.0	
	9	28	44.0	
			27.9	chronometer fast.
Local mean time of fourth contact . .	9	28	16.1	

The time of the last contact I think may be considerably in error, as my eye was fatigued by constant observing, which was begun too early to ensure a result entirely satisfactory.

There was little time to make observations of a general nature. I did, however, notice that that part of the inner corona opposite

to the crescent of the sun was distinctly visible for several seconds before totality. During totality Mercury shone brightly and Venus was plainly visible a few degrees above the eastern horizon.

Part IV. Report of Observations.

By DANA P. BARTLETT.

Although magnetic observations were considered in the early plans for the eclipse work, it was not anticipated that much attention could be devoted to them, as it was not certain that the party would be large enough so that an observer could be spared. It was decided, however, to include magnetic instruments with the other apparatus, and to give to them whatever attention was possible, more particularly also with the idea of taking up this work if the weather should prove unfavorable for the other observations. Previous to May 28 the only magnetic results obtained were those recorded by Mr. Hosmer, on page 170; but, after all our preparations were completed, it was found that an observer could be spared, and the writer was accordingly detailed to observe whether any disturbance in declination occurred during the progress of the eclipse. A description of the apparatus used, and its location, has been given in a previous portion of this report, and will not be repeated here.

On the morning of the eclipse, the magnetometer was set up and adjusted, and every precaution taken to protect it from all local disturbance. Observations were begun about half an hour before the first contact, and readings were recorded at intervals until an hour after the last contact, but except during the interval of totality the instrument was under practically continuous observation throughout the entire period. Between the second and third contacts no readings were obtained, as the scale, not being artificially illuminated, could not be seen. The character and period of vibration of the magnet, however, were such that it is certain that no disturbance other than that indicated by the immediately preceding and succeeding readings occurred during this interval. Each recorded reading represents the careful observation of several successive vibrations of the magnet.

MAGNETOMETER OBSERVATIONS.

Station, Washington, Ga. Date, May 28, 1900. Observer, D. P. B.

Watch Time.	Scale Reading.		Watch Time.	Scale Reading.	
	Right.	Left.		Right.	Left.
h. m. 7 22	39.5	40.7	3d contact.	42.0	42.7
7 26	39.6	40.8	h. m. 8 55	42.2	42.8
7 28	39.2	41.0	9 10	41.7	43.0
7 30	39.8	40.8	9 25	41.7	42.4
1st contact.	40.0	40.7	9 40	42.0	42.2
8 00	40.8	41.0	4th contact.	41.8	42.9
8 20	41.0	42.0	10 15	42.3	42.8
8 30	41.3	42.2	10 30	42.3	43.4
2d contact.	41.3	42.8	11 00	42.1	44.1

Scale reading of axis of magnet = 41.5.
One division of the scale = 1.7′ of arc.

OBSERVATIONS FOR CORRECTION OF THE WATCH.

	h. m. s.	h. m. s.
Watch	11 15 28.5	11 17 28.5
Chronometer, Bond 528	10 45 00.0	10 47 00.0
Difference	30 28.5	30 28.5
Chronometer correction		— 27.9
Watch correction. (Local mean time) .		— 30 56.4

REDUCED MAGNETOMETER OBSERVATIONS.

Local Mean Time.	Scale Reading.	Local Mean Time.	Scale Reading.
h. m. 6 51	40.1	3d contact.	42.4
6 55	40.2	h. m. 8 24	42.5
6 57	40.1	8 39	42.4
6 59	40.3	8 54	42.0
1st contact.	40.4	9 09	42.1
7 29	40.9	4th contact.	42.4
7 49	41.5	9 44	42.6
7 59	41.8	9 59	42.8
2d contact.	42.0	10 29	43.1

From these results we obtain the following plot:

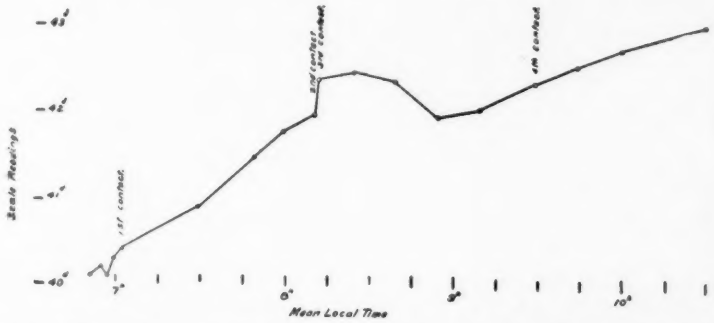


FIG. 12.—CURVE SHOWING CHANGES IN DECLINATION DURING THE TIME OF ECLIPSE.

An inspection of this figure shows at once that a disturbance in declination was produced by the oncoming of the eclipse. The effect first becomes noticeable from twenty to thirty minutes after the first contact, and disappears again at approximately the same time before the last contact. The maximum rate of change occurred between the second and third contacts, and in this interval the declination changed four-tenths of a scale unit, or seven-tenths of a minute of arc.

DECLINATION COMPUTATIONS.

Circle reading during observations . . .	B 208° 56′ 20″		
	A 56′ 00″		
	Mean =		208° 56′ 10″.
Circle reading on Meridian mark . . .	B 207° 51′ 00″		
	A 50′ 40″		
	Mean =		207° 50′ 50″.
Difference			1° 5′ 20″
Scale reading of magnet axis	41.5		
Scale reading at 6*h*. 51*m*. A.M.	40.1		
Position of magnet axis	1.4	=	2′ 23″
Declination at 6*h*. 51*m*. A.M., local mean time .			1° 7′ 43″ E.
Increase in scale reading at 10*h*. 29*m*. = 3.0 .		=	5′ 06″
Declination at 10*h*. 29*m*. A.M., local mean time,			1° 2′ 37″ E.

A STUDY OF CERTAIN SHADES AND GLOBES FOR ELECTRIC LIGHTS, AS USED IN INTERIOR ILLUMINATION.

By WILLIAM LINCOLN SMITH, S.B.

Part I.

Received July 12, 1900.

A. Preliminary Remarks.

Two features which, perhaps more than all others, serve to distinguish our modern artificial sources of illumination from those of older date, are, first, the smallness of the flame or light-giving body, and, second, the high intrinsic brilliancy of the same.

The Welsbach incandescent mantle and the Acetylene flame are examples of gas-using apparatus, and the electric arc and incandescent filament of apparatus perhaps more widely used.

On account of these distinguishing features of modern lights, it becomes imperative to use in connection with them, for purposes of general illumination (omitting, of course, such special purposes as lighthouse work, various kinds of signal lights, and in general, all cases where a concentrated, brilliant ray is desired), some form of shade or enclosing globe which shall cut down the intrinsic brilliancy, and, if possible, concentrate the softened light in those directions or upon those objects where illumination is particularly desired.

While there are many interesting and important points to be considered in connection with the problem of satisfactory illumination of interiors, it is not proposed to do more than touch briefly upon them here, the reader being referred to the various published works upon the subject, and to a series of articles begun about the first of May, 1900, by Dr. Louis Bell, in the *Electrical World*, published in New York.

We should aim emphatically to avoid the production of alternate spots of light and darkness, such as are frequently noticed when a

naked arc is used over a street well shaded with trees, since the strain put upon the eye by constant endeavor to adjust for the varying conditions is very severe. On the other hand, we must sedulously avoid the production of absolutely *uniform* illumination and the consequent total suppression of all shadows, as in this case the eye will be deprived of its principal guide to the judging of distances and proportions of objects with a resulting strain fully as severe as that resulting from the other extreme. We get an illustration of this on those happily rare occasions when the sun is high in the heavens but the sky is veiled by a very thin white cloud, which, although not sufficient to materially diminish the brilliancy of the light, yet causes absolute diffusion and the obliteration of all shadow. The light enters the eye in unwonted quantity from unwonted directions, and the exhausting nature of the effect produced is well known.

It is a fortunate fact for us in our attempts to produce satisfactory illuminations, that the eye does not depend upon the *absolute* illumination of bodies; but that the absolute illumination of a landscape or room may vary within very wide limits, and, provided the *relative* illumination of the several parts remains unchanged, the eye will still be satisfied.

Again, it is a fact, though apparently unknown to many, that for the majority of purposes, a well distributed *moderate* illumination is far superior for results obtained, and comfort and ease of the eye, than a decidedly brighter and more concentrated illumination. The reason is, that in the first case the eye is able to work with a larger aperture and the muscles in a more easy state, while in the second case the aperture is stopped far down and the muscles more tense and strained.

Nevertheless, the average person is more prone to transgress rules of health and comfort in the matter of illumination than in many another less important matter. As a salesman of a large supply house said to me some time since in regard to a certain shade, "We know perfectly well that that is one of the best and most satisfactory patterns we handle, but you can't make the average buyer believe it."

The average person is not satisfied with a good, soft, well-distributed illumination; he wants something with more size to it, a big glare for his money. He would never dream of allowing direct sunlight to fall upon his desk, but he will deliberately hang a good-sized incandescent light over his work, about a foot in front of him

and a foot above his head, so that every time he raises his eyes they meet that bright spot.

Again, he will work, or be made to work, at a desk thus lighted by a single lamp, a green paper or tin shade put upon it to concentrate the light downward, and the rest of the room in consequent gloom, so that every time he looks away from his work the eye passes from light to shade, and back again, with the resulting strain upon it, so that after a little while another person has to be fitted with glasses.

The remedy is, of course, simple, and there exists no excuse for neglecting it. If a bright light is needed localized upon a desk or table, this should be superposed upon a moderate general illumination of the room, so that the decided contrast of light and shade is prevented. Or, if only the single desk light is to be burned, it should be fitted with some type of shade which, while projecting the greater part of the light downward upon the work, will still allow a sufficient amount to escape to produce a mild illumination of the surroundings. In any case, the light should be so placed as to be out of the field of view of the worker under all ordinary conditions.

Some years ago, before the introduction of modern high power sources of light, the position and arrangement of artificial lights according to each person's pleasure or whim made little difference. Fixtures and lamps could be arranged any way (subject only to the requirements of combustion); they could be used by the architect or decorator to "dress up the walls," and for other purposes wholly aside from their sole reason for being — *i. e.*, supply of artificial illumination — or, as was still more often the case, they could be put wherever the gasfitter found it most convenient to punch a hole in the wall. The introduction of electric lighting made the state of affairs still worse, because these lamps could be put upside down, or any other way, at will.

It is hardly too much to say that the ordinary person does not know enough to properly arrange his own lights — the average wireman certainly does not — and that the architect and interior decorator too frequently will not, because he still is carried away with the desire to use fixtures and lights for decorative purposes, more or less in defiance of scientific considerations. This use for decoration of interiors is legitimate certainly, provided it is not allowed to mask the true purpose of the sources of light, so as to make them rather sources of torment than of light to the unfortunates who may be forced to sit

near them, and who have mind and soul distracted from their proper occupations for the time being, in the vain attempt to avoid dazzle or glare and allow the eyes to take in surrounding objects in peace and comfort.

As a matter of fact, the source of light ought to be invisible, or else so toned down as to be unobtrusive, and its presence simply inferred from the general excellence of illumination produced by it; for it is a self-evident fact that we only desire to *see the light source in the single case of signal lights, and in all other cases we desire to see an object or objects by the aid of the light-source*, for which purpose the source itself should be outside the field of view.

Since, in the vast majority of cases, it would be either exceedingly inconvenient or expensive to hide the source of light completely, it has become customary to leave it exposed (and frequently in the field of view), but to fit it with a shade of some kind, so as to render it more unobtrusive and more suitable for the purpose at hand.

Shades may be classified into:

1. Those which aim to be simply ornamental, and which being nothing else, will not be considered further.

2. Those which aim to cut down the light and diffuse it more or less.

3. Those which aim not to diffuse the light, but simply to concentrate it in certain directions.

4. Those which aim to both diffuse the light and also to distribute it in certain directions.

There is an enormously large number of shades upon the market, the vast majority of which have no other reason for being than to satisfy the whims of their makers, and the individual idiosyncrasies of the hoped-for purchaser. How whimsical they are, and how little the particular pattern of any one has to recommend it, is shown by the recognized difficulty of replacing, a year or so after purchase, any one of a set which may have become broken.

A small minority remain on the market through a number of years, because they have become, as it were, standard patterns, and are simple, such as plain, frosted, and opal globes of various tints.

A still smaller number remain because they, in a more or less satisfactory manner, do the work for which they were designed, and do it comparatively well and fairly efficiently, one, at least, remarkably efficiently.

The following series of tests were made upon a number of the leading types of shades and globes for electric lights, by no means exhaustive of available styles, but still, it is believed, fairly representative, and form part of a more extended study of illumination which it is hoped to continue the present winter.

The results here given will be found to be based principally upon Mean Spherical Candle-power. I am well aware that this quantity has been made too much of in the past, and that it is not always nor most frequently the best standard of comparison, since it is not the quantity with which we are most frequently and directly concerned. I think, however, that at the present stage of the investigation, it is the best standard of comparison, and almost the only one available for the purpose in hand. At a later stage, others will present themselves and prove to be more convenient and satisfactory.

B. Types of Shades Tested.

1. Holophane Pendant, one-piece sphere, Cat. No. 3,550.
2. Holophane Pendant, one-piece sphere, Cat. No. 3,551.
3. Holophane Stalactite, Class A, Cat. No. 3,354.
4. Holophane Stalactite, Class B, $5\frac{1}{2}''$ x $8''$, Cat. No. 3,250.
5. Holophane Stalactite, Class B, $4''$ x $6''$, Cat. No. 3,150.
6. The same style Holophane, but with old style of cutting.
7. Holophane Upright one-piece sphere, Cat. No. 3,105.
8. Holophane Pendant Tulip, $3\frac{1}{2}''$ x $5\frac{1}{4}''$, Cat. No. 2,251.
9. Holophane Pendant Tulip, $4\frac{1}{2}''$ x $5\frac{1}{4}''$, Cat. No. 2,250.
10. $9''$ x $3\frac{1}{4}''$ Stalactite Prism.
11. $9''$ x $3\frac{1}{4}''$ Canary Stalactite.
12. $9''$ x $3\frac{1}{4}''$ Opaline Stalactite.
13. "M" Prismatic Tulip.
14. $7''$ McCreary Shade.
15. $6''$ Ball Pendant, upper hemisphere opal and lower hemisphere clear glass, with a many-rayed star cut in the bottom of it.
16. A E. G. 50 C. P. 112 v. spherical bulb coiled filament lamp. Coil of filament in centre of bulb, and basal hemisphere of bulb silvered on the outside.
17. Same lamp, with silver minor removed.
18. $8''$ Deep Tin Cone, white enamel inside.
19. $6''$ Deep Cone, fluted porcelain.

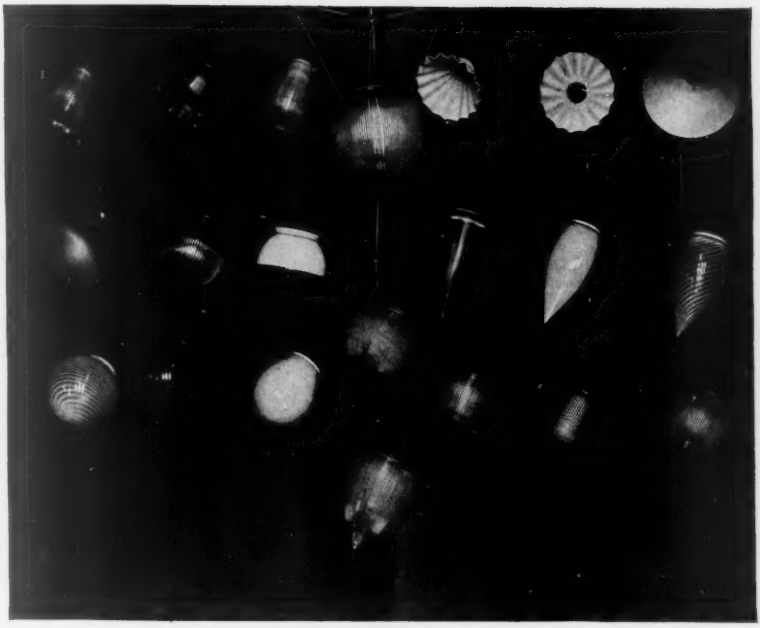
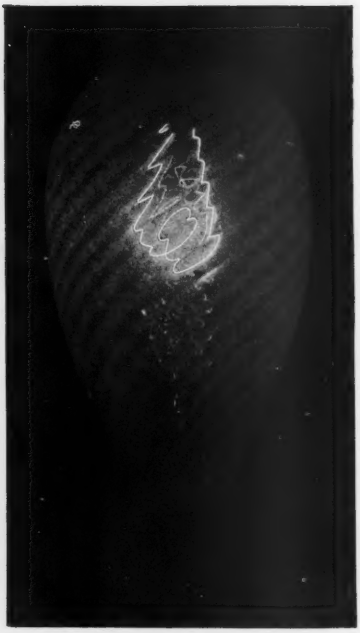


FIG. 1. — GROUP OF SHADES, UNILLUMINATED.

9	13	8	1	19	20	18
14	22	15	2	10	11	12
24	21	23	4	5	6	7

FIG. 2. — CANARY STALACTITE.



OPALINE STALACTITE.

FIG. 3. — HOLOPHANE STALACTITE, NO. 3250.

STALACTITE PRISM.

20. 6″ Flat Cone, fluted porcelain.
21. 6″ Ground Glass Ball.
22. 6″ Prismatic Glass Ball.
23. 6″ Opal Ball.
24. 6″ Opaline Ball.

Figure 1 is a group of these shades unilluminated.

Figures 2 and 3 show the four large stalactites, namely, Numbers 4, 10, 11, and 12, of the table, as they appear when lighted from within. The effect of the shades when studied together with the distribution curves is very evident. The Canary Stalactite simply cuts the light down slightly, affecting no redistribution, and the filament remains perfectly and unpleasantly in evidence. The Opaline Stalactite does not reduce the light so much, and does not produce so unpleasant an effect, but neither does it redistribute. The effect is to produce an appearance of the filament, as though it were reflected in a rippling surface of water. The Stalactite Prism is comparatively ineffective, and there appears a double image of the filament, just distinguishable in the cut, but very prominent in the actual shade. The Holophane, however, glows all over uniformly, and there is almost complete diffusion. Moreover, there is redistribution downward, which causes the lower portion to appear darker when viewed from the angle at which the camera was placed. This shade *ought* to be fitted to a 32 C. P. light, but for purposes of comparison it was used with the same lamp as the others, none of which would admit of using larger than a 16 C. P.

The first nine shades are made of the so-called Holophane glass, which aims at both diffusion and directive action on the rays of light given off by the enclosed lamp. It accomplishes its results by two systems of cutting, one on the inner and the other on the outer surface of the shade. That on the inner is a system of ribs, running vertically, shown in cross-section (section on a horizontal plane) in Figure 4.

The outside system of cutting consists of parallel prisms, one above the other, covering the whole outer surface of the shade. Each circular prismatic ring has its angles determined by its position on the shade and the deflecting effect desired of the shade as a whole. Each prism has a compound surface, one part acting by refraction and the other by total reflection. This system of cutting is shown in Figure 5, which is a section on a vertical plane. The inside system produces

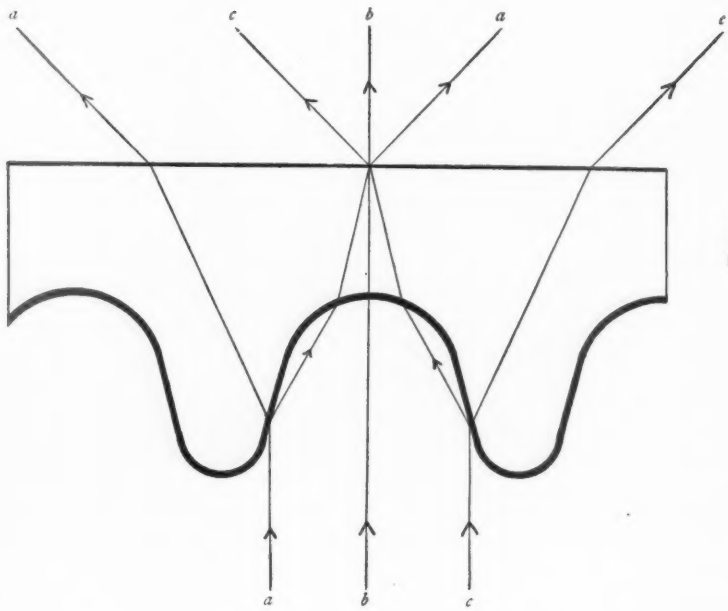


FIG. 4.

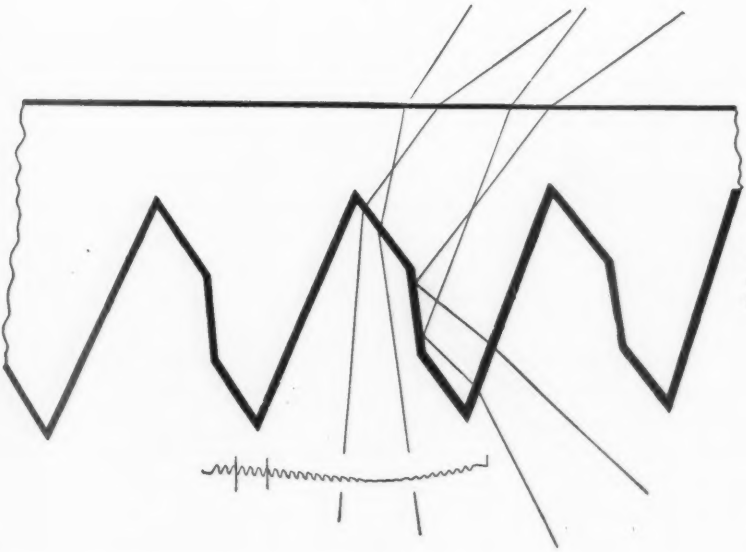


FIG. 5.

diffusion, and the outside system produces the desired deflecting of the various rays, the shade itself being made of clear glass. This type of shade is thoroughly well worked out on accurate lines, is very efficient, and produces a most pleasing illumination, soft and powerful; the source of light appears to be a large, mildly glowing surface of sparkling points, very unobtrusive, it being possible to see readily and comfortably past the light. The shade is also free from spectral bands of color, which occasionally appear with some other types.

Number 10 is a shade which might by some be mistaken for a Holophane, but its interior ribs are simply V slots, and its outer prisms totally different. It is not at all in the same class.

Numbers 11 and 12 are both very common, the first being a long, graceful stalactite of a canary-yellow color, and the second similarly shaped, of a pale blue opalescence, with spiral flutings running about it from tip to base.

Number 13 is a small, bell-shaped shade, just large enough to take an ordinary 16 candle-power lamp. The upper quarter of the shade is clear glass with slight markings on it; the central half a band with very fine V-shaped flutings running horizontally in circles about the outside, and vertically upon the inside; while the lower quarter of the shade is again clear glass.

Number 14 is a well-known type.

Number 15 is a very peculiar pattern, — a ball, with the lower half of clear glass with a large star-shaped figure cut in it, the centre of the figure being at what might be called the south pole of the ball, and producing upon the surface of table or floor below, curiously unpleasant striations of light and shade. The upper half, containing the hole and flange for holding the lamp and socket, is a thick, milk-white opal.

The remainder of the shades are all common types, and require no description.

C. Method of Testing.

Three lamps were chosen, all general electric, rated at 112 volts, and respectively 16, 32, and 50 candle-power. These lamps were carefully tested unshaded, and then fitted with the various shades as desired. Four of the shades, however, as noted further on, were tested upon a Bryan and Marsh lamp, as the 16 C. P. G. E. was unfortunately broken. Measurements were made upon a 200-inch

photometer bar very thoroughly screened, and all stray light was thus eliminated. Of course, we must realize that when the shaded lamps are upon the photometer the source of light is no longer a point, or even approximately one, and hence the law of inverse squares is no longer strictly true.

The plan of wiring of the apparatus is shown in Figure 6, and is evident from the drawing. The circuit passed from the main switch

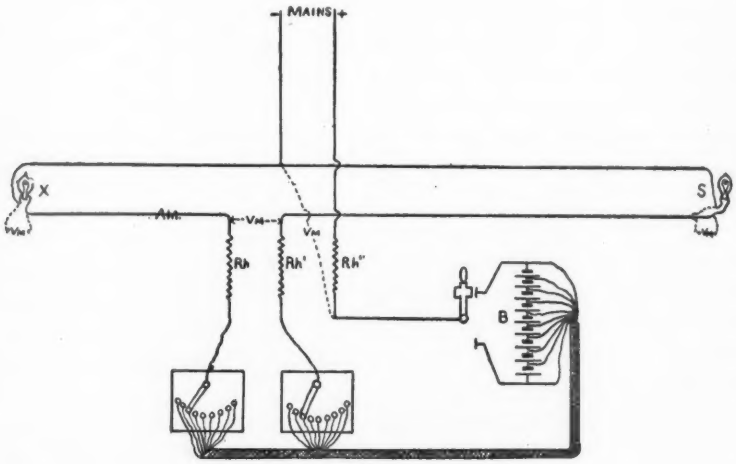


FIG. 6.

through a variable carbon resistance, Rh″, to one end of a storage battery B, arranged for either positive or negative boost, and from the battery through a pair of selecting switches to two more carbon resistances, Rh and Rh′, the circuit from one of these going to one end of the bar, the circuit from the other, to the opposite end. At the right-hand end of the bar was the holder for the incandescent lamp, serving as the secondary standard, and at the left end of the bar two separate holders, one controlled by hand for setting the lamp under test at any desired angle of latitude and longitude, the other rotated by a motor for the making of spinning measurements. Loops were left for the insertion of ammeters, and voltmeter leads were brought from the *lamp terminals*, the mains, and the differential point between the two lamps. All wiring was done with No. 00 wire between the lamps, so that the drop, except in the carbon resistances, was negligibly small,

and would still remain so when the circuits were carrying current for good-sized series lamps.

Suppose, then, that it was desired to test a 120-volt lamp using a 104-volt standard. We would connect the 110-volt mains to the apparatus, and by means of the selector switches and storage battery, bring the pressure at the terminals of the 120-volt lamp to approximately that amount. Then, by means of the carbon resistances in series with the two lamps, adjust the pressure of one to exactly 120, and of the other to exactly 104.

The voltmeter could now be put across the mains, and if the pressure rose or fell above 110, thus raising or lowering the pressure at the two lamps proportionately, it could be brought back, if desired, by the carbon resistance, Rh″, first mentioned as inserted in the main before it reached the point of branching to the two lamps.

It is, however, unnecessary that this pressure at the mains should remain absolutely fixed, since it is well known that so long as the two lamps remain at the proper *relative* pressures, the *absolute* pressure may vary within moderate limits without affecting the ratio of the two lights, provided the lamps are of approximately the same efficiency. The correctness of the relative pressures could be checked at any time by simply putting the voltmeter across the differential points between the two lamps, when it should measure (in this supposed case) 120 — 104 = 16 volts, and in case it did not, the lamp which had changed could be detected and the change corrected.

The lamp to be tested was then placed in the hand-controlled holder, and the candle-power measured for every 30 degrees around the equator of the lamp. The candle-power was then measured for every 30 degrees on four meridians of the lamp, namely, those on longitude 0°, 45°, 90°, and 135°, thus allowing of the plotting of curves of horizontal distribution and four equally spaced curves of vertical distributions. These curves give to the eye a very good idea of the distribution of light from the lamp. It would be simple to calculate from them the quantity called the Mean Spherical Candle-power, which is used in comparing the various tests, and which may be defined as the "sum of the illuminations received by a sphere of radius unity concentric with the light-source, divided by the surface of this sphere." I preferred to determine it, however, by a separate test, as follows: The lamp was placed in the spinning apparatus, and readings taken every 15 degrees from tip to base, thus giving thirteen

equally spaced readings of mean candle-power at the several angles, and enabling a curve of distribution to be plotted, as in Figure 7, which is the curve for the Canary Stalactite. If, then, we measure the area of the right-hand curve of Figure 7, and also that of the enclosing rectangle; take the ratio of these and multiply the maximum ordinate by this ratio; the result will be the Mean Spherical Candle-power desired.[1]

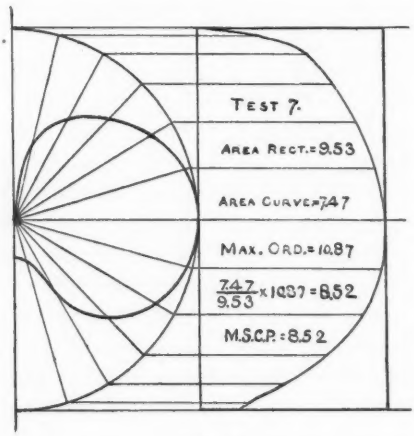


FIG. 7.

D. STANDARDS OF LIGHT USED.

The primary standard used was a Hefner-Alteneck lamp, burning acetate of amyl, made by Krüss, numbered 796, and bearing the Reichsanstalt certificate No. 430. This is usually assumed to be equivalent, under proper working conditions, to .885 standard candles. I compared it against twelve standard candles, using a 100-inch bar and a Lummer Brodhun screen, and obtained a mean value of .869 candles.

The secondary standard which was used throughout the tests was a special aged incandescent lamp run at 112 volts, and giving in the marked direction, as compared with the Hefner lamp, a value of 10.57 candle-power, this value being the mean of twelve tests.

[1] Palaz, A. Treatise on Industrial Photometry. Trans. by Patterson. Ed. 2. New York, 1896.

These tests were made at about equal intervals throughout the course of the work and the mean value used in the calculations.

Voltage was measured on a Weston voltmeter, No. 4,915, which has been carefully kept and calibrated frequently; its error at 112 volts (the voltage used in all this work) was + 0.14 volts.

Current was measured on two Weston ammeters, No. 1,856, reading to 1.0 ampere and with negligible error, the other, No. 384, reading to 5.0 amperes and having a zero error of + .05 ampere.

In the calibration of the secondary standard a Lummer-Brodhun screen was used, but throughout the rest of the work a Bunsen disc, which had in previous work proved very satisfactory, was made use of, as it was far more convenient and satisfactory for my purpose.

E. Sample of Tests.

The following six tables form the complete record of readings taken for one test, namely, the first made upon the Canary Stalactite, the plot of mean spherical candle-power for which (the data for this plot being found in table 7*f* following) has already been referred to in Figure 7. Three tests, similar to the one given here, were made upon each shade, and the final results given are invariably the mean of these three, except in the one case of the A. E. G. spherical bulb lamp, where the silver minor was taken off before I had an opportunity to make check tests. In this case, also, the tests given were made as part of the regular laboratory work by two students, who were, however, very careful workers. The test on this lamp made after removal of the silver I was able to check, and found no serious discrepancies. All the other tests here recorded were made by myself, although in several cases the lamp or shade was further tested by students, and checking results obtained; these, however, are not given.

PHOTOMETRIC TEST NO. 7*a*.

Date of test, May 23, 1900.

Type of lamp, G.E., 112 v. 16 C. P. (marked Test lamp No. 2, 1900 W. L. S.).

Type of shade, 9″ x 3¼″, Canary Stalactite.

Instruments used, Weston Voltmeter, No. 4,915, error = + 0.14. Weston Ammeter, No. 1,856; error negligible. Bunsen Disc A.

Standards of light used: Primary, Hefner Lamp, No. 796; Certificate No. 430. Secondary, Aged Incandescent Lamp, calibrated as 10.57 candle-power.

DISTRIBUTION IN HORIZONTAL PLANE THROUGH EQUATOR.

Angles.	Observed Ratios.				Mean ratio.	Candle power.	Volts.	Amperes.
	1.	2.	3.	4.				
0°	1.030	1.025	1.035	1.030	1.030	10.9	112.0	.496
30°	1.025	1.030	1.030	1.040	1.032	10.9	112.0	.496
60°	1.035	1.024	1.030	1.030	1.030	10.9	112.0	.496
90°	1.035	1.035	1.025	1.040	1.034	10.9	112.0	.497
120°	1.030	1.035	1.030	1.035	1.033	10.9	112.0	.495
150°	1.025	1.020	1.025	1.035	1.026	10.8	112.0	.496
180°	1.035	1.030	1.025	1.040	1.034	10.9	112.0	.495
210°	1.028	1.035	1.035	1.038	1.034	10.9	112.0	.496
240°	1.032	1.035	1.038	1.037	1.035	10.9	112.0	.496
270°	1.024	1.028	1.030	1.028	1.027	10.8	112.0	.497
300°	1.025	1.030	1.031	1.028	1.028	10.9	112.0	.496
330°	1.020	1.025	1.030	1.035	1.028	10.9	112.0	.496
0°	1.025	1.031	1.034	1.029	1.031	10.9	112.0	.496

PHOTOMETRIC TEST NO. 7*b*.

Date of test, May 23, 1900.

Type of lamp, G. E., 112 v. 16 C. P. (marked Test lamp No. 2, 1900 W. L. S.).

Type of shade, 9″ x 3¼″, Canary Stalactite.

Instruments used, Weston Voltmeter, No. 4,915, error = + 0.14. Weston Ammeter, No. 1,856; error negligible. Bunsen Disc A.

Standards of light used: Primary, Hefner Lamp, No. 796, Certificate No. 430. Secondary, Aged Incandescent Lamp, calibrated as 10.57 candle-power.

DISTRIBUTION IN VERTICAL PLANE THROUGH 0° LONG.

Angles.	Observed Ratios.				Mean ratio.	Candle power.	Volts.	Amperes.
	1.	2.	3.	4.				
0°	1.027	1.029	1.035	1.030	1.030	10.89	112.0	.496
30°	.905	.904	.901	.907	.904	9.56	112.0	.497
60°	.440	.435	.440	.435	.437	4.62	112.0	.497
90°	.206	.207	.208	.205	.207	2.19	112.0	.496
120°	.445	.450	.445	.440	.445	4.71	112.0	.496
150°	.910	.905	.907	.905	.907	9.59	112.0	.495
180°	1.025	1.030	1.035	1.031	1.031	10.90	112.0	.496
210°	.900	.904	.902	.900	.902	9.54	112.0	.495
240°	.665	.672	.675	.678	.675	7.14	112.0	.496
270°	....	....	....	....	....	....	....	....
300°	.665	.670	.666	.665	.667	7.04	112.0	.496
330°	.895	.890	.898	.895	.896	9.47	112.0	.496
0°	1.035	1.030	1.027	1.027	1.031	10.90	112.0	.496

PHOTOMETRIC TEST No. 7*c*.

Date of test, May 23, 1900.

Type of lamp, G. E., 112 v. 16 C. P. (marked Test lamp No. 2, 1900 W. L. S.).

Type of shade, 9″ x 3¼″, Canary Stalactite.

Instruments used, Weston Voltmeter, No. 4,915, error = + 0.14. Weston Ammeter, No. 1,856, error negligible. Bunsen Disc A.

Standards of light used: Primary, Hefner Lamp, No. 796, Certificate No. 430. Secondary, Aged Incandescent Lamp, calibrated as 10.57 candle-power.

DISTRIBUTION IN VERTICAL PLANE THROUGH 45° LONG.

Angles.	Observed Ratios.				Mean ratio.	Candle power.	Volts.	Amperes.
	1.	2.	3.	4.				
0°	1.035	1.030	1.030	1.025	1.030	10.89	112.0	.496
30°	.906	.904	.900	.908	.905	9.57	112.0	.496
60°	.460	.465	.470	.465	.465	4.92	112.0	.496
90°	.208	.207	.206	.207	.207	2.19	112.0	.497
120°	.465	.467	.463	.465	.465	4.92	112.0	.497
150°	.905	.910	.904	.906	.906	9.58	112.0	.496
180°	1.030	1.035	1.035	1.030	1.032	10.91	112.0	.495
210°	.880	.884	.885	.884	.883	9.34	112.0	.496
240°	.600	.605	.605	.605	.604	6.39	112.0	.496
270°	....	....	....	....	....	....	....	....
300°	.600	.605	.610	.611	.607	6.42	112.0	.494
330°	.885	.889	.892	.884	.887	9.38	112.0	.497
0°	1.035	1.031	1.030	1.029	1.031	10.90	112.0	.496

PHOTOMETRIC TEST NO. 7*d*.

Date of test, May 23, 1900.

Type of lamp, G. E., 112 v. 16 C. P. (marked Test lamp No. 2, 1900 W. L. S.).

Type of shade, 9″ x 3¼″, Canary Stalactite.

Instruments used, Weston Voltmeter, No. 4,915, error = + 0.14. Weston Ammeter, No. 1,856, error negligible. Bunsen Disc A.

Standards of light used: Primary, Hefner Lamp, No. 796, Certificate No. 430. Secondary, Aged Incandescent Lamp, calibrated as 10.57 candle-power.

DISTRIBUTION IN VERTICAL PLANE THROUGH 90° LONG.

Angles.	Observed Ratios.				Mean ratio.	Candle power.	Volts.	Amperes.
	1.	2.	3.	4.				
0°	1.035	1.037	1.035	1.030	1.034	10.94	112.0	.496
30°	.905	.908	.908	.905	.906	9.58	112.0	.497
60°	.485	.495	.495	.498	.493	5.22	112.0	.496
90°	.208	.207	.206	.207	.207	2.19	112.0	.496
120°	.475	.480	.475	.485	.479	5.06	112.0	.495
150°	.905	.900	.905	.899	.902	9.54	112.0	.495
180°	1.025	1.025	1.024	1.026	1.025	10.84	112.0	.496
210°	.865	.875	.875	.875	.873	9.23	112.0	.496
240°	.531	.530	.532	.526	.529	5.59	112.0	.495
270°	....	....	....	....	....	....	....	....
300°	.525	.530	.525	.529	.527	5.57	112.0	.496
330°	.875	.880	.880	.878	.878	9.28	112.0	.497
0°	1.030	1.035	1.035	1.034	1.033	10.92	112.0	.497

PHOTOMETRIC TEST No. 7*e*.

Date of test, May 23, 1900.

Type of lamp, G. E., 112 v. 16 C. P. (marked Test lamp No. 2, 1900 W. L. S.).

Type of shade, 9″ x 3¼″, Canary Stalactite.

Instruments used, Weston Voltmeter, No. 4,915, error = + 0.14. Weston Ammeter, No. 1,856, error negligible. Bunsen Disc A.

Standards of light used: Primary, Hefner Lamp, No. 796, Certificate No. 430. Secondary, Aged Incandescent Lamp, calibrated as 10.57 candle-power.

DISTRIBUTION IN VERTICAL PLANE THROUGH 135° LONG.

Angles.	Observed Ratios.				Mean ratio.	Candle power.	Volts.	Amperes.
	1.	2.	3.	4.				
0°	1.024	1.026	1.025	1.030	1.026	10.85	112.0	.495
30°	.907	.905	.910	.907	.907	9.59	112.0	.495
60°	.465	.465	.470	.462	.466	4.93	112.0	.497
90°	.206	.207	.208	.207	.207	2.19	112.0	.496
120°	.464	.461	.462	.458	.461	4.87	112.0	.496
150°	.910	.911	.902	.900	.906	9.58	112.0	.497
180°	1.030	1.027	1.027	1.020	1.026	10.85	112.0	.496
210°	.885	.884	.880	.879	.882	9.33	112.0	.497
240°	.610	.605	.610	.608	.608	6.43	112.0	.496
270°	....	....	....	....	....	....	....	....
300°	.607	.605	.605	.610	.607	6.42	112.0	.495
330°	.882	.880	.879	.886	.802	8.48	112.0	.496
0°	1 030	1 027	1.027	1 025	1.027	10.86	112.0	.496

PHOTOMETRIC TEST No. 7*f*.

Date of Test, May 23, 1900.

Type of lamp, G. E., 112 v. 16 C. P. (marked Test lamp No. 2, 1900 W. L. S.).

Type of shade, 9″ x 3¼″, Canary Stalactite.

Instruments used, Weston Voltmeter, No. 4,915, error = + 0,14. Weston Ammeter, No. 1,856, error negligible. Bunsen Disc A.

Standards of light used: Primary, Hefner Lamp, No. 796, Certificate, No. 430. Secondary, Aged Incandescent Lamp, calibrated as 10.57 candle-power.

MEAN VERTICAL DISTRIBUTION.

Angles.	Observed Ratios.				Mean ratio.	Candle power.
	1.	2.	3.	4.		
0°	.207	.207	.207	.207	.207	2.19
15°	.235	.236	.236	.236	.236	2.50
30°	.463	.462	.464	.463	.463	4.90
45°	.732	.730	.733	.733	.732	7.75
60°	.905	.906	.906	.906	.906	9.59
75°	.998	1.000	.999	.995	.998	10.55
90°	1.027	1.027	1.030	1.028	1.028	10.87
105°	.993	.993	.993	.993	.993	10.50
120°	.874	.875	.874	.873	.874	9.25
135°	.752	.753	.752	.753	.752	7 95
150°	.600	.601	.600	003	.601	6.36
165°	.426	.426	.426	.423	.425	4.50
180°	....	....	....	....	....	0.0

This table is for plot used in determining the Mean Spherical Candle-power. 0° means the tip of the shade, and 180° means the base. The resulting curve is that previously given in Figure 7.

F. Results of Tests.

The following table gives the results obtained from the different shades, and is self-explanatory. The numbers in the upper row refer to the number of the shade in the list previously given, — those in the bottom row to the plate on which the distribution plots will be found. The standard position of the lamp was with the plane of the shanks of the filament at right angles to the photometer bar, the side of the

Number of Shade.	A.	B.	C.	D.									
	G. E., 16 C. P. Test lamp.	G. E., 50 C. P. Test lamp.	G. E., 32 C. P. Test lamp.	B-M., 16 C. P. Test lamp.	2.	3.	10.	13.	14.	11.	4.	4A.	15.
Mean Spherical candle-power	**11.28**	**31.00**	**21.90**	**13.50**	**26.70**	**18.70**	**7.81**	**10.07**	**7.50**	**8.52**	**9.45**	**27.90**	**8.63**
Mean Horizontal candle-power	14.07	37.20	27.30	16.80	30.60	16.10	9.65	10.39	2.29	10.90	8.51	34.70	3.20
Mean Standard reading	13.34	36.10	27.10	16.83	30.70	16.00	9.76	11.40	2.29	10.90	8.51	35.00	3.23
Spherical ÷ Standard	.846	.860	.808	.802	.848	1.17	.800	.884	3.28	.782	1.11	.796	2.67
Horizontal ÷ Standard	1.05	1.03	1.01	.998	.998	1.01	.989	.912	1.00	1.00	1.00	.992	.992
Spherical ÷ Horizontal	.803	.834	.803	.804	.850	1 16	.809	.969	3.28	.782	1.11	.805	2.69
Per cent. of absorption	....	....	....	....	**13.8**	**14.6**	**30.8**	**10.1**	**33.5**	**24.4**	**16.2**	**10.0**	**23.5**
Per cent. of light thrown below equator	50.9	50.2	50.4	50.4	55.8	63.2	53.4	56.9	90.9	49.4	54.2	62.6	73.0
Per cent. of light thrown above equator	49.1	49.8	49.6	49.6	44.2	36.8	46.6	43.1	9.1	50.6	45.8	37.4	27.0
Maximum candle-power	....	....	....	....	31.50	34.97	9.82	15.22	42.72	10.90	11.47	38.10	17.98
Angle of Maximum candle-power	**0°**	**0°**	**0°**	**0°**	**—15°**	**—90°**	**0°**	**—60°**	**—90°**	**0°**	**—45°**	**—35°**	**—90°**
Volts on lamp	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0
Amperes in lamp	.496	1.51	.996	.501	1.51	.995	.495	.495	.496	.496	.496	1.51	.496
Watts in lamp	55.6	169.	111.6	56.1	169.	111.5	55.4	55.4	55.6	55.6	55.6	169.	55.6
Watts per Mean Spherical candle-power,	**4.92**	**5.46**	**5.10**	**4.15**	**6.33**	**5.96**	**7.10**	**5.50**	**7.41**	**6.52**	**5.88**	**6.06**	**6.44**
Watts per Mean Horizontal candle-power	3.94	4.55	4.09	3.34	5.52	6.93	5.75	5.29	24.3	5.10	6.54	4.87	17.4
Watts per Maximum candle-power	....	....	....	....	5.37	3.19	5.64	3 64	1.30	5.10	4.85	4.44	3.09
Compare with test lamp	....	....	....	....	B.	C.	A.	A.	A.	A.	A.	B.	A.
Plot on plate number	1	....	....	....	2	3	4	5	6	7	8	9	10

Number of Shade.	6.	5.	16.	17.	7.	8.	9.	19.	18.	20.	21.	22.	23.	24.
Mean Spherical candle-power	**9.39**	**10.06**	**19.10**	**24.60**	**9.92**	**10.14**	**10.07**	**9.89**	**8.12**	**9.84**	**10.20**	**10.73**	**9.15**	**10.38**
Mean Horizontal candle-power	12.00	11.40	7.85	28.90	10.48	12 32	12.00	5.26	0.0	13.94	13.08	15.65	10.05	12.50
Mean Standard reading	11.88	10.94	9.90	30.35	10.46	12.30	11.99	5.34	0.0	13.96	12.92	15.25	10.05	13.20
Spherical ÷ Standard	.790	.920	1.93	.811	.948	.825	.841	1.85	....	.704	.790	.704	.912	.787
Horizontal ÷ Standard	1.01	1.04	.793	.952	1.00	1.00	1.00	.985	....	.999	1.01	1.03	1.00	.948
Spherical ÷ Horizontal	.782	.884	2.43	.852	.946	.824	.840	1.88	....	.706	.780	.686	.912	.831
Per cent. of absorption	**16.8**	**10.8**	**22.3**	....	**12.1**	**10.1**	**10.8**	**12.4**	**28.1**	**12.8**	**24.4**	**20.7**	**32.2**	**23.0**
Per cent. of light thrown below equator	60.2	61.8	100.0	53.2	57.6	59.6	59.2	69.4	100.	74.0	53.6	54.0	50.0	54.5
Per cent. of light thrown above equator	39.8	38.6	0	46.8	42.4	40.4	40.8	30.6	0.0	26.0	46.4	46.0	50.0	45.5
Maximum candle-power	12.11	12.51	74.77	28.90	13.55	12.92	13.04	18.15	29.49	15.72	13.08	15.65	10.05	12.60
Angle of Maximum candle-power	**—20°**	**—40°**	**—90°**	**0°**	**—35°**	**—40°**	**—60°**	**—40°**	**—90°**	**—30°**	**0°**	**0°**	**0°**	**—10°**
Volts on lamp	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0	112.0
Amperes in lamp	.496	.496	1.20	1.20	.497	.497	.497	.497	.497	.497	.500	.501	.501	502
Watts in lamp	55.6	55.6	134.4	134.4	55.7	55.7	55.7	55.7	55.7	55.7	56.0	56.1	56.1	56.2
Watts per Mean Spherical candle-power,	**5.92**	**5.52**	**7.04**	**5.46**	**5.61**	**5.50**	**5.53**	**5.63**	**6.86**	**5.66**	**5.49**	**5.22**	**6.13**	**5.42**
Watts per Mean Horizontal candle-power	4.63	4.87	17.2	4.65	5.31	4.52	4.64	10.6	....	3.99	4.28	3.57	5.58	4.50
Watts per Maximum candle-power	4.60	4.44	1.80	4.65	4.11	4.31	4.27	3.07	1.89	3.54	4.28	3.57	5.58	4.46
Compare with test lamp	A.	A.	17	16	A.	A.	A.	A.	A.	A.	D.	D.	D.	D.
Plot on plate number	11	13	12	12	14	15	16	17	18	19	20	21	22	23

lamp chosen being marked with a cross, and the "mean standard reading" is the mean of all readings made when the lamp under test occupied the above position. Accordingly, in each test, the lamp within the shade occupied the same position at each angular setting that it did in the test of the naked lamp, so that in this regard the plots are directly comparable. It was found, however, impossible to plot them all on one scale, and accordingly the value of the candle-power at the tip of lamp or shade is recorded on each plot, *i.e.*, at the 90° point, in all cases except that of No. 7 (the Upright Holophane Sphere), where the position is reversed and the tip of the lamp occurs at 270°.

The only plates to which further reference is necessary are as follows:

Plate I. This shows the curves obtained from the G. E. 112 v. 16 C. P. Test Lamp used with the majority of shades. The two tests given were made one before and the other after the work, and no change in the lamp was found. Since all the otner test lamps have practically the same shaped curves, it has not been thought worth while to plot them.

Plate III contains not only the curve obtained with the 32 C. P. lamp, but also on the same scale the plots for the same shade with a 16 C. P. lamp.

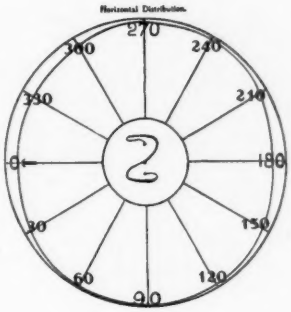
Plate XII gives both curves for the A. E. G. lamp, the broken line curves being taken with the silvering in place and the solid curves with it removed. These, again, are on the same scale.

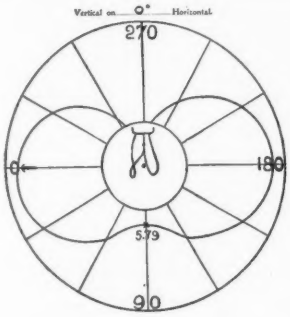
TEST LAMP 27

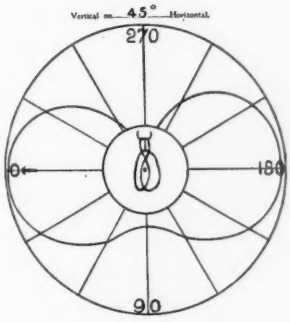
Number of Test 1-27	NAKED	NAKED
Mean Spherical Candle Power	11.28	11.30
Mean Horizontal Candle Power	14.07	14.09
Mean Standard Readings	13.34	13.34
Ratio Spherical to Standard	.846	.848
Ratio Horizontal to Standard	1.05	1.06
Ratio Spherical to Horizontal	.803	.802
Percent Absorption	—	—
Percent Light thrown below Equator	50.9	50.8
Percent Light thrown above Equator	49.1	49.2
Angle of Maximum Candle Power	0°	0°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.497
Watts in Lamp	55.4	55.7
Watts per Mean Spherical Candle Power	4.91	4.93
Watts per Mean Horizontal Candle Power	3.94	3.95

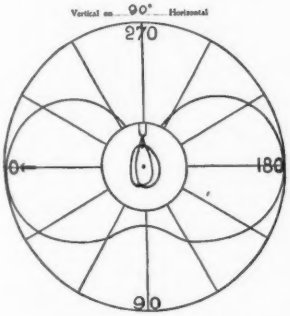
_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power.
_____ Circle Shows Mean Horizontal Candle Power.

Lamp Used C.E. 112 v. 16 C.P.
Shade Used NONE USED
Standard Used AGED INCAND.
Date of Test MAY 3, 1900 to JUNE 7, 1900
Remarks There is the lamp upon which the great: ss part of the shades were placed. Till two tests were made one before and the other after the room on the shades were made.









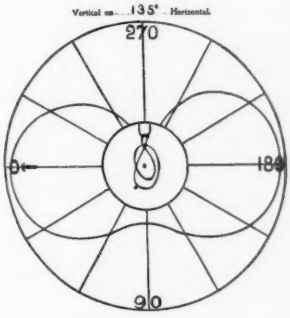


PLATE I.—CURVES FROM G. E. 112 V. 16 C. P. TEST LAMP, WITHOUT SHADE.

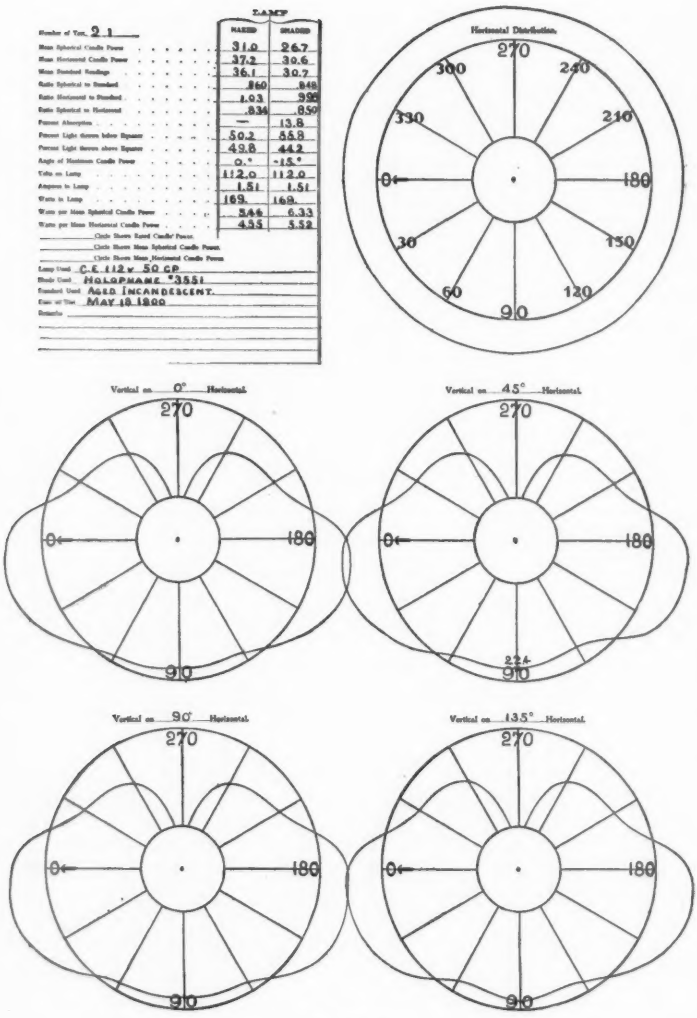

LAMP
NAKED
SHADED
Number of Test 2 1
Mean Spherical Candle Power 31.0 26.7
Mean Horizontal Candle Power 37.2 30.6
Mean Standard Readings 36.1 30.7
Ratio Spherical to Standard .860 .848
Ratio Horizontal to Standard 1.03 .932
Ratio Spherical to Horizontal .834 .850
Percent Absorption — 13.8
Percent Light thrown below Square 50.2 55.8
Percent Light thrown above Square 49.8 44.2
Angle of Maximum Candle Power 0.° -15.°
Volts on Lamp 112.0 112.0
Amperes in Lamp 1.51 1.51
Watts in Lamp 169. 169.
Watts per Mean Spherical Candle Power 5.46 6.33
Watts per Mean Horizontal Candle Power 4.55 5.52
Circle Shows Rated Candle Power.
Circle Shows Mean Spherical Candle Power.
Circle Shows Mean Horizontal Candle Power.
Lamp Used C.E. 112 v 50 CP
Shade Used HOLOPHANE #3551
Standard Used ALLEG. INCANDESCENT.
Date of Test MAY 18 1900
Remarks
Horizontal Distribution.
270
300
240
330
210
0
180
30
150
60
120
90
Vertical on 0° Horizontal.
270
0
180
90
Vertical on 45° Horizontal.
270
0
180
224
90
Vertical on 90° Horizontal.
270
0
180
90
Vertical on 135° Horizontal.
270
0
180
90

PLATE II.

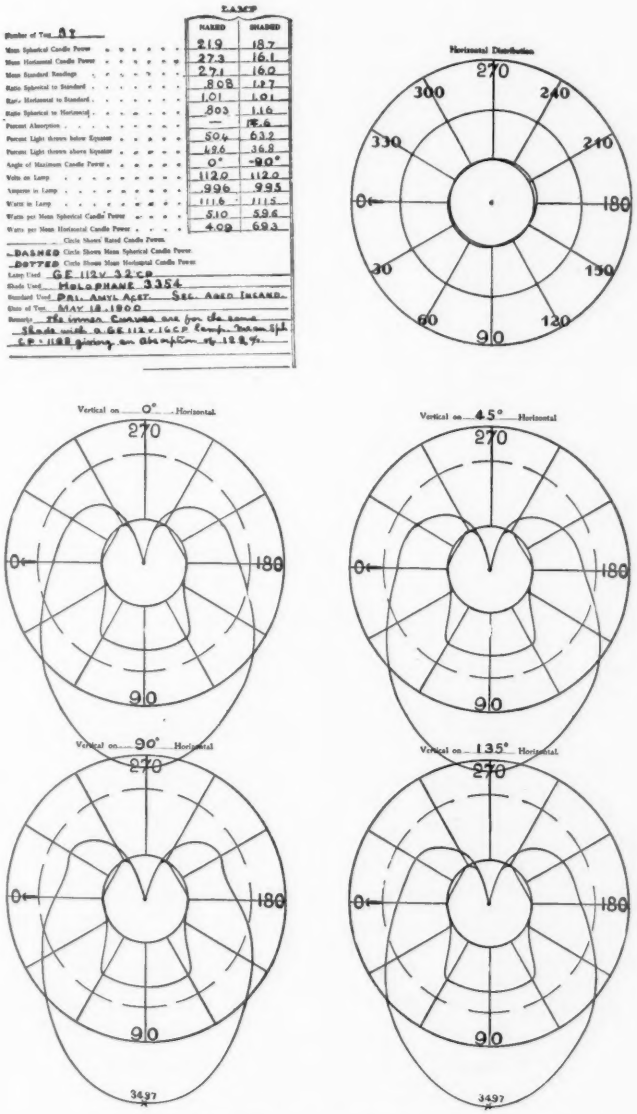


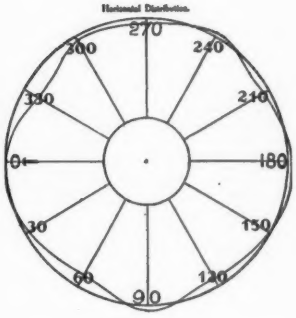
PLATE III. — SHADE, HOLOPHANE 3,354.
OUTER CURVE OBTAINED WITH 32 C. P. LAMP, INNER CURVE WITH 16 C. P. LAMP.

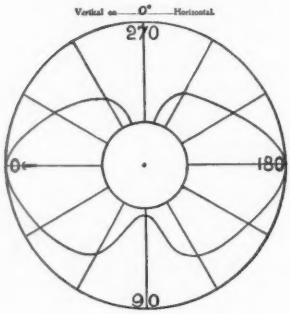
LAMP

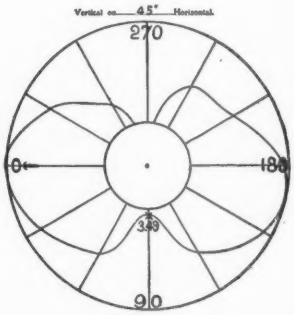
Number of Test 41	BARED	SHADED
Mean Spherical Candle Power	1128	781
Mean Horizontal Candle Power	1407	965
Mean Standard Readings	1334	876
Ratio Spherical to Standard	.846	.800
Ratio Horizontal to Standard	1.05	.989
Ratio Spherical to Horizontal	.803	.809
Percent Absorption		30.8
Percent Light thrown below Equator	50.9	53.4
Percent Light thrown above Equator	49.1	46.6
Angle of Maximum Candle Power	0°	0°
Volts on Lamp	1120	1120
Amperes in Lamp	.496	.495
Watts in Lamp	556	554
Watts per Mean Spherical Candle Power	492	710
Watts per Mean Horizontal Candle Power	3.94	5.75

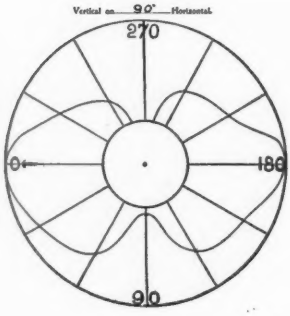
_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power.
_____ Circle Shows Mean Horizontal Candle Power.

Lamp Used GE 112 v 16CP
Shade Used 9¾" STLACTITE PRISM.
Standard Used AGED INCAND. LAMP C.P.=16.7
Date of Test MAY 21 1909.
Remarks









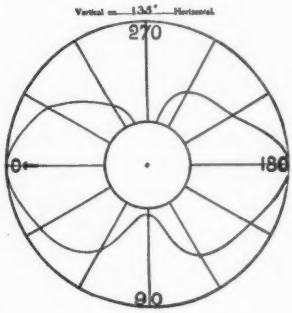


PLATE IV.

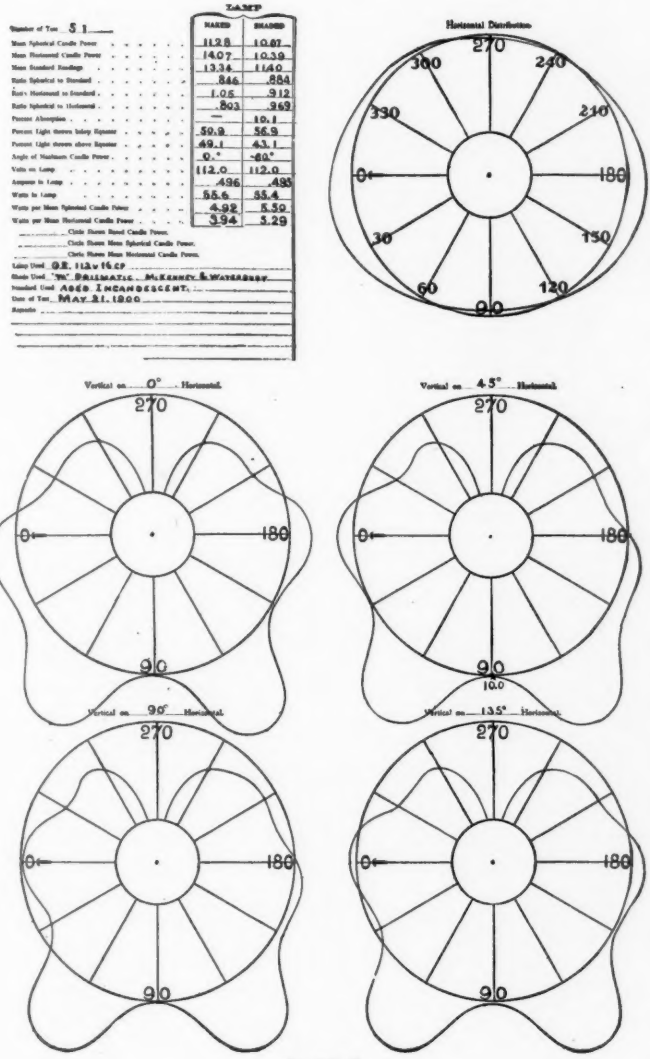
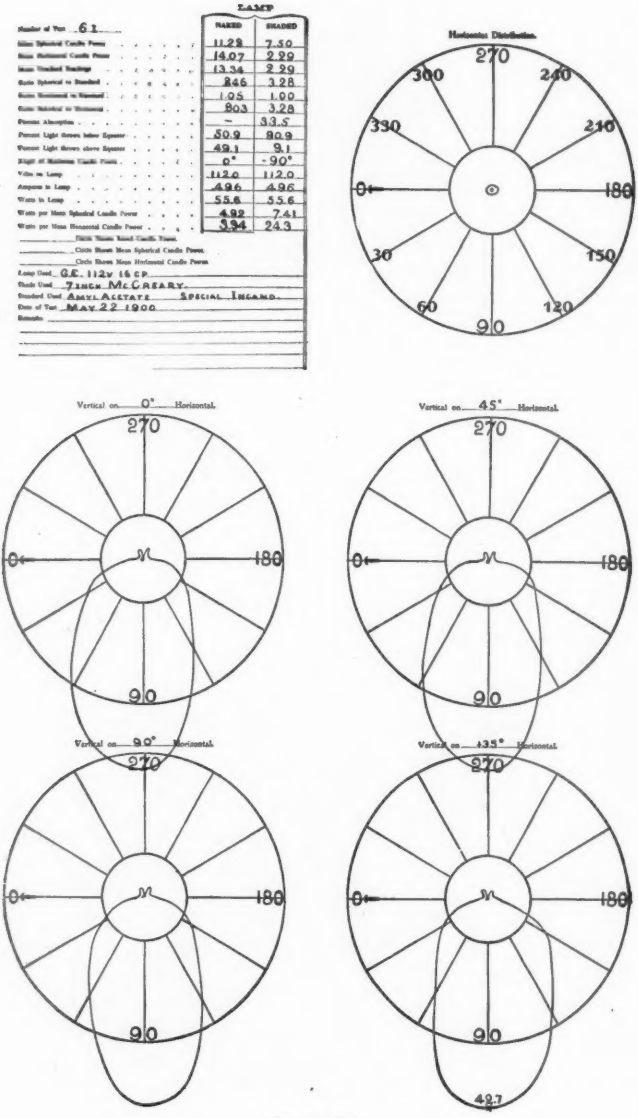

Lamp
Number of Test S 1
NAKED
SHADED
Mean Spherical Candle Power 112.8 10.67
Mean Horizontal Candle Power 14.07 10.39
Mean Standard Readings 13.34 11.40
Ratio Spherical to Standard .846 .884
Ratio Horizontal to Standard 1.05 .912
Ratio Spherical to Horizontal .803 .969
Percent Absorption — 10.1
Percent Light thrown below Equator 50.9 56.9
Percent Light thrown above Equator 49.1 43.1
Angle of Maximum Candle Power 0.° 60°
Volts on Lamp 112.0 112.0
Amperes in Lamp .496 .495
Watts in Lamp 55.6 55.4
Watts per Mean Spherical Candle Power 4.92 5.19
Watts per Mean Horizontal Candle Power 3.94 5.29
Circle Shows Mean Spherical Candle Power.
Circle Shows Mean Horizontal Candle Power.
Lamp Used 92, 112 v 16 cp
Shade Used "W" Prismatic, McKenney & Wayeabrey
Standard Used Arco Incandescent.
Date of Test May 21, 1900
Remarks
Horizontal Distribution
270
300
240
330
210
0
180
30
150
60
120
90
Vertical on 0° Horizontal.
270
0
180
90
Vertical on 45° Horizontal.
270
0
180
90
10.0
Vertical on 90° Horizontal.
270
0
180
90
Vertical on 135° Horizontal.
270
0
180
90

PLATE V.



LAMP

	NAKED	SHADED
Number of Test 61		
Mean Spherical Candle Power	11.28	7.50
Mean Horizontal Candle Power	14.07	2.29
Mean Hemispherical Readings	13.34	2.29
Ratio Spherical to Standard	.846	3.28
Ratio Horizontal to Standard	1.05	1.00
Ratio Spherical to Horizontal	.803	3.28
Percent Absorption	—	33.5
Percent Light thrown below Equator	50.9	90.9
Percent Light thrown above Equator	49.1	9.1
Angle of Maximum Candle Power	0°	-90°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.496
Watts in Lamp	55.6	55.6
Watts per Mean Spherical Candle Power	4.92	7.41
Watts per Mean Horizontal Candle Power	3.94	24.3
Sixth Mean Rated Candle Power		
Circle Mean Mean Spherical Candle Power		
Circle Mean Mean Horizontal Candle Power		

Lamp Used G.E. 112v 16 CP

Shade Used Tinch McCreary

Standard Used Amyl Acetate Special Incand.

Date of Test May 22 1900

Remarks

Horizontal Distribution.

270 300 240 330 210 0 180 30 150 60 120 90

Vertical on 0° Horizontal.

270 0 180 90

Vertical on 45° Horizontal.

270 0 180 90

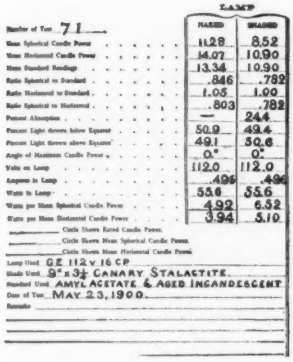
Vertical on 90° Horizontal.

270 0 180 90

Vertical on 135° Horizontal.

270 0 180 90 42.7

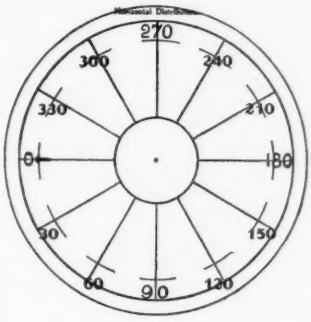
PLATE VI.

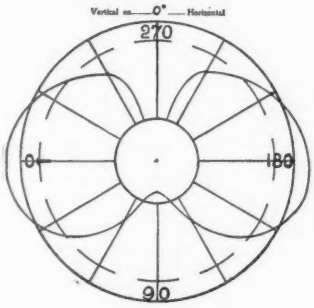

LAMP

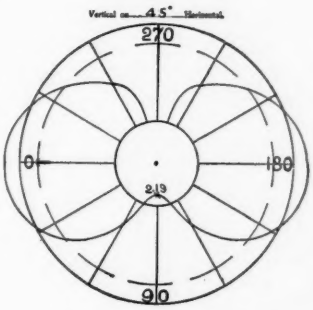
	BARED	SHADED
Number of Test 71		
Mean Spherical Candle Power	11.28	8.52
Mean Horizontal Candle Power	14.07	10.90
Mean Standard Readings	13.34	10.90
Ratio Spherical to Standard	.846	.782
Ratio Horizontal to Standard	1.05	1.00
Ratio Spherical to Horizontal	.803	.782
Percent Absorption	—	24.4
Percent Light thrown below Equator	50.9	49.4
Percent Light thrown above Equator	49.1	50.6
Angle of Maximum Candle Power	0°	0°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.496
Watts in Lamp	55.6	55.6
Watts per Mean Spherical Candle Power	4.92	6.52
Watts per Mean Horizontal Candle Power	3.94	5.10

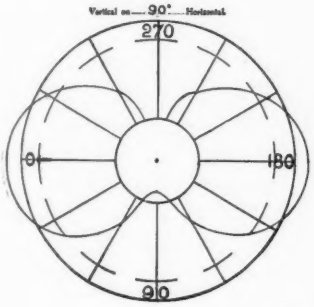
——— Circle Shows Rated Candle Power.
——— Circle Shows Mean Spherical Candle Power.
——— Circle Shows Mean Horizontal Candle Power.

Lamp Used GE 112 v 16 CP
Shade Used 9" x 3½ CANARY STALACTITE
Standard Used AMYL ACETATE & AGED INCANDESCENT
Date of Test MAY 23, 1900
Remarks









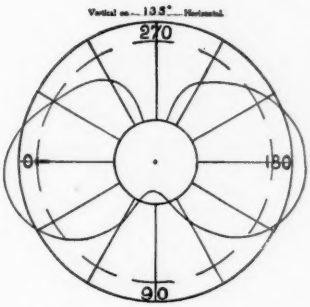


PLATE VII.

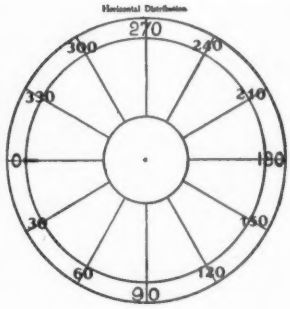
Number of Test 81

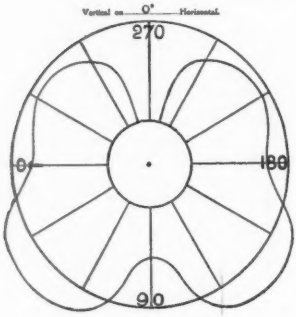
LAMP

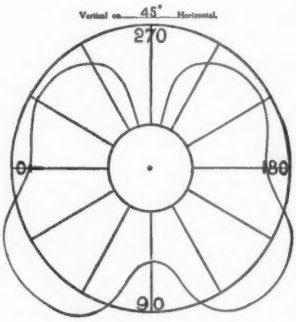
	BARED	SHADED
Mean Spherical Candle Power	11.28	9.45
Mean Horizontal Candle Power	14.07	8.51
Mean Standard Readings	13.84	8.51
Ratio Spherical to Standard	.846	1.11
Ratio Horizontal to Standard	1.05	1.00
Ratio Spherical to Horizontal	.803	1.11
Percent Absorption		16.2
Percent Light thrown below Equator	50.9	54.2
Percent Light thrown above Equator	49.1	45.8
Angle of Maximum Candle Power	0°	-45°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.496
Watts in Lamp	55.6	55.6
Watts per Mean Spherical Candle Power	4.92	5.88
Watts per Mean Horizontal Candle Power	3.94	6.54

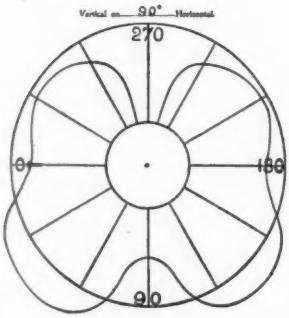
_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power.
_____ Circle Shows Mean Horizontal Candle Power.

Lamp Used GE 112v 16 CP
Shade Used HOLOPHANE STALACTITE 3250
Standard Used AGED INCANDESCENT
Date of Test MAY 24, 1900.
Remarks









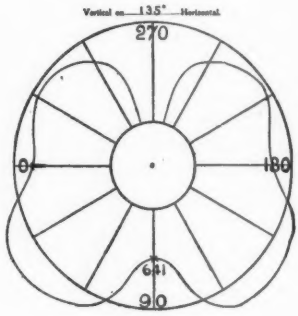


PLATE VIII.

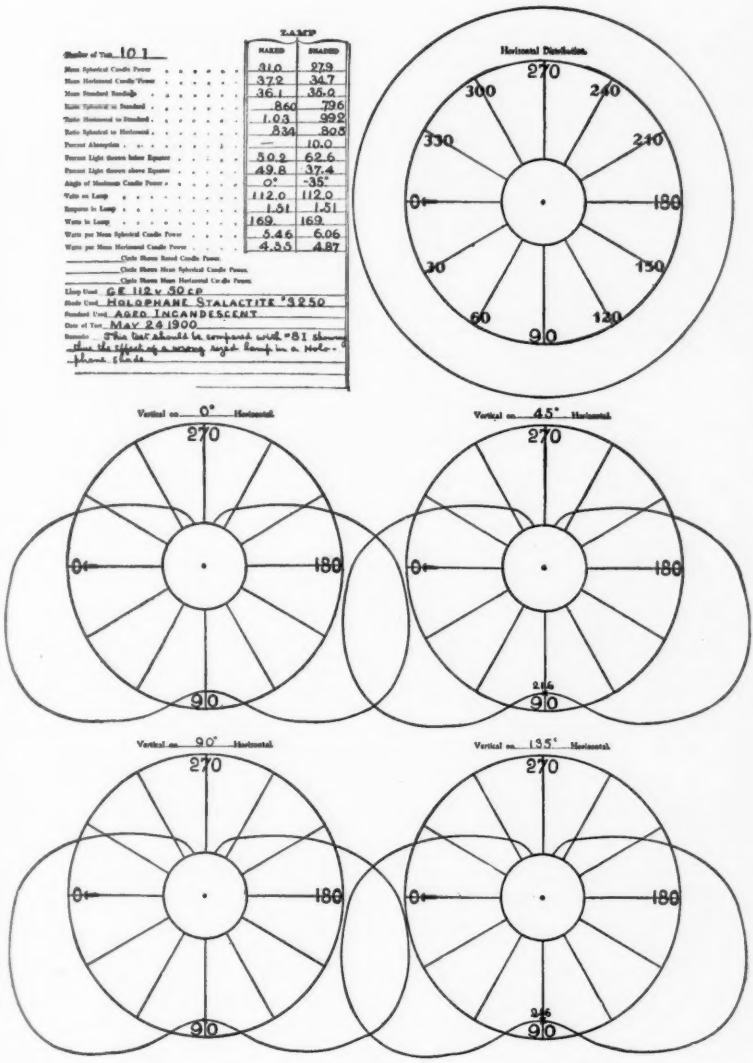

LAMP
BARED
SHADED
Number of Test 101
Mean Spherical Candle Power 310 279
Mean Horizontal Candle Power 372 347
Mean Standard Candle 361 350
Ratio Spherical to Standard 860 796
Ratio Horizontal to Standard 1.03 992
Ratio Spherical to Horizontal 834 805
Percent Absorption — 10.0
Percent Light thrown below Equator 50.2 62.6
Percent Light thrown above Equator 49.8 37.4
Angle of Maximum Candle Power 0° -35°
Volts on Lamp 112.0 112.0
Amperes in Lamp 1.51 1.51
Watts in Lamp 169. 169.
Watts per Mean Spherical Candle Power 5.46 6.06
Watts per Mean Horizontal Candle Power 4.55 4.87
Circle Shows Rated Candle Power.
Circle Shows Mean Spherical Candle Power.
Circle Shows Mean Horizontal Candle Power.
Lamp Used GE 112 v 50 cp
Shade Used HOLOPHANE STALACTITE #3250
Standard Used AGED INCANDESCENT
Date of Test MAY 24 1900
Remarks This test should be compared with #81 showing the effect of a wrong angle lamp in a Holophane shade.
Horizontal Distribution
270
300
240
330
210
0
180
30
150
60
120
90
Vertical on 0° Horizontal
270
0
180
90
Vertical on 45° Horizontal
270
0
180
246
90
Vertical on 90° Horizontal
270
0
180
90
Vertical on 135° Horizontal
270
0
180
246
90

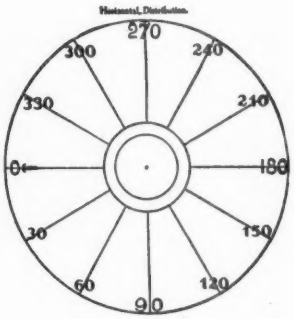
PLATE IX.

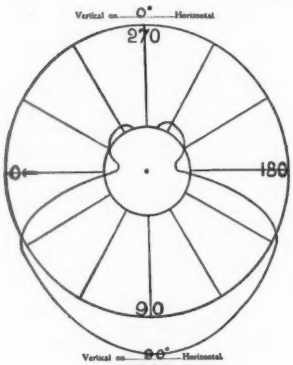
LAMP

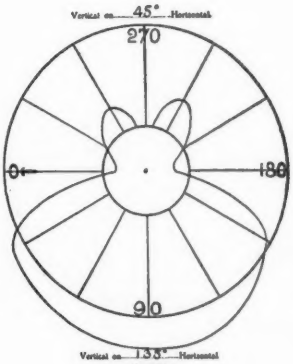
	NAKED	SHADED
Number of Test 111		
Mean Spherical Candle Power	1128	8.63
Mean Horizontal Candle Power	1407	3.20
Mean Hemidial Readings	1334	3.23
Ratio Spherical to Standard	.846	2.67
Ratio Horizontal to Standard	1.05	.992
Ratio Spherical to Horizontal	.803	2.69
Percent Absorption		23.5
Percent Light thrown below Equator	50.9	73
Percent Light thrown above Equator	49.1	27
Angle of Minimum Candle Power	0°	-90°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	4.96
Watts in Lamp	55.6	55.6
Watts per Mean Spherical Candle Power	492	644
Watts per Mean Horizontal Candle Power	3.94	17.4

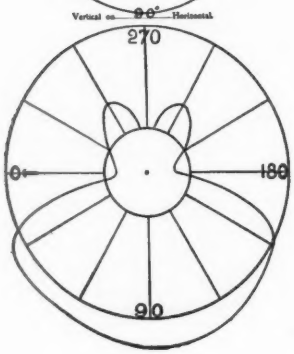
_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power.
_____ Circle Shows Mean Horizontal Candle Power.

Lamp Used GE 112 v 16 CP
Shade Used ½ OPAL 6 INCH BALL
Standard Used AGED INCANDESCENT
Date of Test MAY 25 1900
Remarks This Shade is a Sphere for pendant use the Upper hemisphere Opal and the Lower clear glass with a star cut in it.









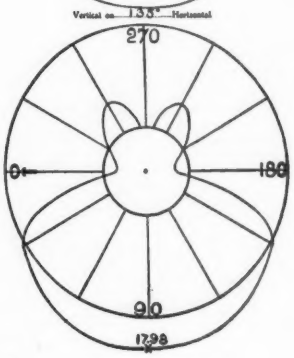
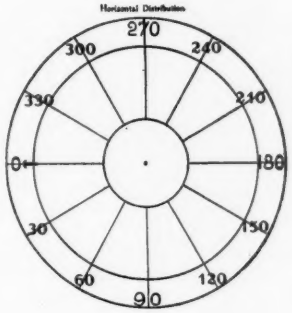


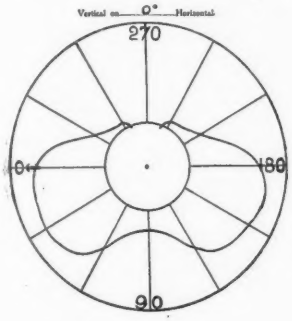
PLATE X.

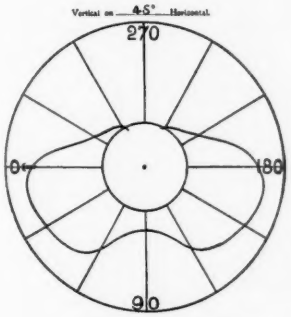
Number of Test 131	LAMP	
	NAKED	SHADED
Mean Spherical Candle Power	0.28	9.39
Mean Horizontal Candle Power	14.07	12.00
Mean Standard Readings	13.34	11.88
Ratio Spherical to Standard	.846	.790
Ratio Horizontal to Standard	1.05	1.01
Ratio Spherical to Horizontal	.803	.782
Percent Absorption	—	16.8
Percent Light thrown below Equator	50.9	60.2
Percent Light thrown above Equator	49.1	39.8
Angle of Maximum Candle Power	0°	-20°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.496
Watts in Lamp	55.6	55.6
Watts per Mean Spherical Candle Power	4.92	5.92
Watts per Mean Horizontal Candle Power	3.94	4.63

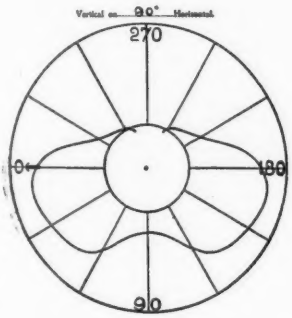
_____ Circle Shows Rated Candle Power
_____ Circle Shows Mean Spherical Candle Power
_____ Circle Shows Mean Horizontal Candle Power

Lamp Used GE 112 v 16 CP
Shade Used HOLOPHANE STALACTITE #3130
Standard Used AGED INCANDESCENT
Date of Test MAY 29 1900
Remarks This Stalactite is not identical with that used in Test 16. But is the old pattern both in shape and cutting, some reflection by the one used in Test 16.









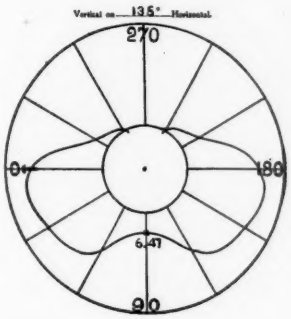
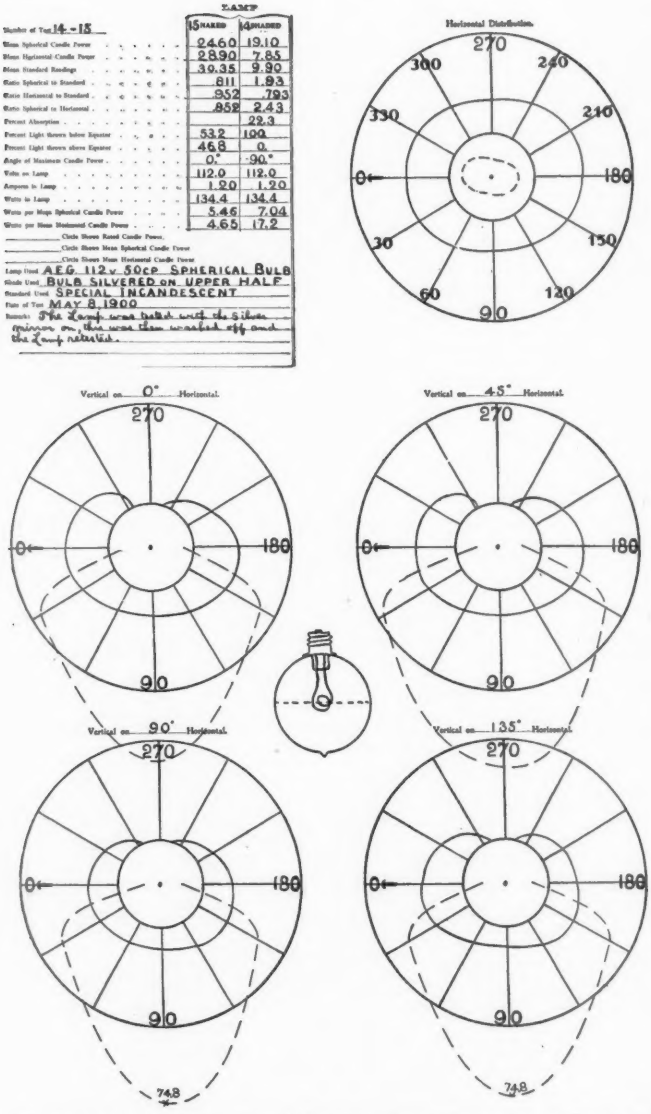


PLATE XI.



LAMP

Number of Test 14 - 15	15 NAKED	14 SHADED
Mean Spherical Candle Power	24.60	19.10
Mean Horizontal Candle Power	28.90	7.85
Mean Standard Readings	30.35	9.90
Ratio Spherical to Standard	.811	1.93
Ratio Horizontal to Standard	.952	.793
Ratio Spherical to Horizontal	.852	2.43
Percent Absorption		22.3
Percent Light thrown below Equator	53.2	100
Percent Light thrown above Equator	46.8	0.
Angle of Maximum Candle Power	0°	90°
Volts on Lamp	112.0	112.0
Amperes in Lamp	1.20	1.20
Watts in Lamp	134.4	134.4
Watts per Mean Spherical Candle Power	5.46	7.04
Watts per Mean Horizontal Candle Power	4.65	17.2

_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power
_____ Circle Shows Mean Horizontal Candle Power

Lamp Used AEG. 112 v. 50 cp. SPHERICAL BULB
Globe Used BULB SILVERED ON UPPER HALF
Standard Used SPECIAL INCANDESCENT
Date of Test MAY 8 1900
Remarks The Lamp terms dotted were the silver. Portion on, the terms then tornafed off and the Lamp retested.

Horizontal Distribution.

270 300 240 330 210 0 180 30 150 60 120 90

Vertical on 0° Horizontal.

270 0 180 90

Vertical on 45° Horizontal.

270 0 180 90

Vertical on 90° Horizontal.

270 0 180 90 748

Vertical on 135° Horizontal.

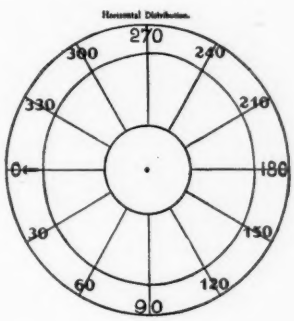
270 0 180 90 748

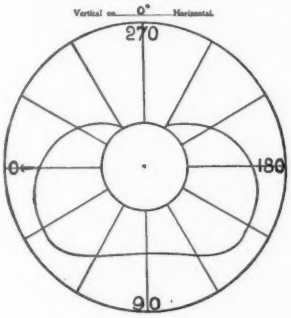
PLATE XII. — SPHERICAL BULB, BROKEN LINE, CURVE WITH SILVERING IN PLACE; SOLID LINE, WITH SILVERING REMOVED.

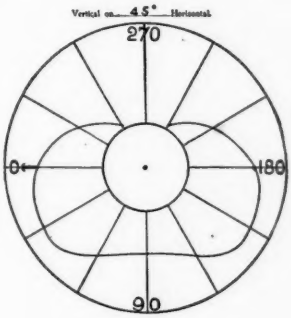
LAMP	NAKED	SHADED
Number of Test 161		
Mean Spherical Candle Power	11.28	10.06
Mean Horizontal Candle Power	14.07	11.40
Mean Standard Readings	13.34	10.94
Ratio Spherical to Standard	.846	.920
Ratio Horizontal to Standard	1.05	1.04
Ratio Spherical to Horizontal	.803	.884
Percent Absorption	—	10.8
Percent Light thrown below Equator	50.9	61.8
Percent Light thrown above Equator	49.1	38.6
Angle of Maximum Candle Power	0°	-40°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.496
Watts in Lamp	55.6	55.6
Watts per Mean Spherical Candle Power	4.92	5.52
Watts per Mean Horizontal Candle Power	3.94	4.87

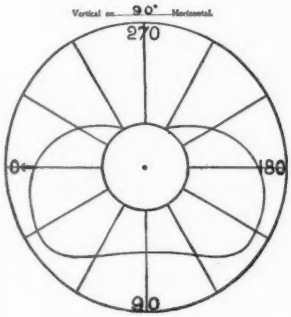
_____ Circle Shows Rated Candle Power
_____ Circle Shows Mean Spherical Candle Power
_____ Circle Shows Mean Horizontal Candle Power

Lamp Used GE 112 v 16 cp
Shade Used HOLOPHANE STALACTITE #3150
Standard Used AGED INCANDESCENT
Date of Test MAY 31, 1900
Remarks









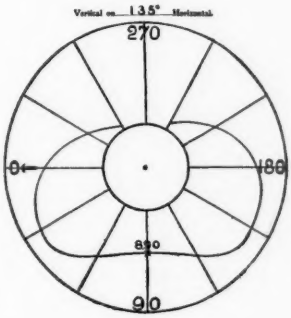


PLATE XIII.

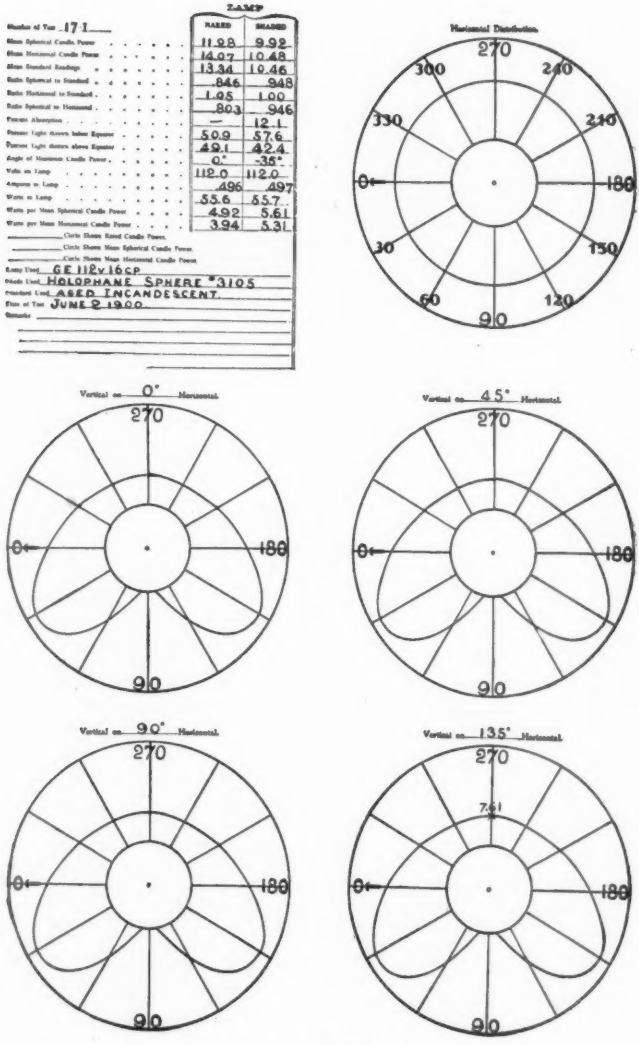

LAMP
NAKED
SHADED
Number of Test 171
Mean Spherical Candle Power 11.98 9.92
Mean Horizontal Candle Power 14.07 10.48
Mean Standard Readings 13.34 10.46
Ratio Spherical to Standard .846 .948
Ratio Horizontal to Standard 1.05 1.00
Ratio Spherical to Horizontal .803 .946
Percent Absorption — 12.1
Percent Light thrown below Equator 50.9 57.6
Percent Light thrown above Equator 49.1 42.4
Angle of Maximum Candle Power 0° -35°
Volts on Lamp 112.0 112.0
Amperes in Lamp .496 .497
Watts in Lamp 55.6 55.7
Watts per Mean Spherical Candle Power 4.92 5.61
Watts per Mean Horizontal Candle Power 3.94 5.31
Circle Shows Rated Candle Power.
Circle Shows Mean Spherical Candle Power.
Circle Shows Mean Horizontal Candle Power.
Lamp Used GE 112v 16cp
Shade Used HOLOPHANE SPHERE #3105
Standard Used AGED INCANDESCENT
Date of Test JUNE 2 1900
Remarks
Horizontal Distribution.
270
300
240
330
210
0
180
30
150
60
120
90
Vertical on 0° Horizontal.
270
0
180
90
Vertical on 45° Horizontal.
270
0
180
90
Vertical on 90° Horizontal.
270
0
180
90
Vertical on 135° Horizontal.
270
7.61
0
180
90

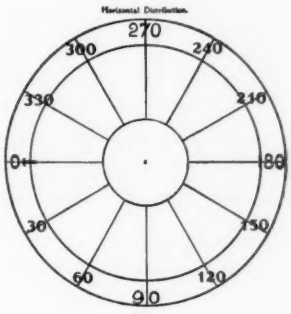
PLATE XIV.

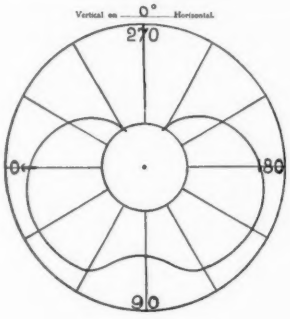
Number of Test 181

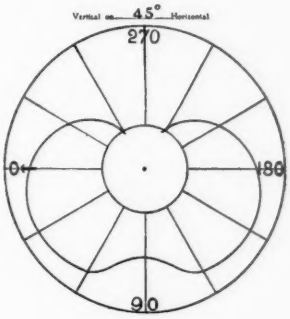
	LAMP	
	BARED	SHADED
Mean Spherical Candle Power	11.98	10.14
Mean Horizontal Candle Power	14.07	12.32
Mean Standard Readings	13.34	12.30
Ratio Spherical to Standard	.846	.825
Ratio Horizontal to Standard	1.05	1.00
Ratio Spherical to Horizontal	.803	.824
Percent Absorption	—	10.1
Percent Light thrown below Equator	50.9	59.3
Percent Light thrown above Equator	49.1	40.7
Angle of Maximum Candle Power	0°	40°
Volts on Lamp	112.0	112.0
Amperes on Lamp	.496	.497
Watts on Lamp	55.6	55.7
Watts per Mean Spherical Candle Power	4.92	5.50
Watts per Mean Horizontal Candle Power	3.94	4.52

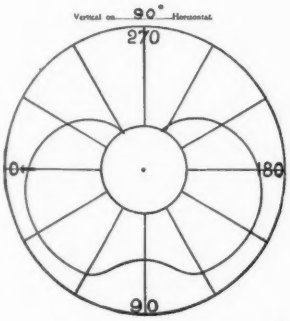
_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power
_____ Circle Shows Mean Horizontal Candle Power

Lamp Used G.E. 112 v 16cp
Shade Used HOLOPHANE TULIP "2251
Standard Used AGED INCANDESCENT
Date of Test JUNE 2 1900
Remarks









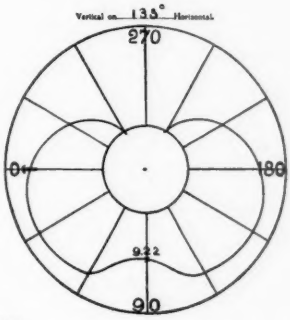


PLATE XV.

LAMP

	BARED	SHADED
Mean Spherical Candle Power	11.88	10.07
Mean Horizontal Candle Power	14.07	12.00
Mean Standard Readings	13.34	11.99
Ratio Spherical to Standard	.846	.841
Ratio Horizontal to Standard	11.05	1.00
Ratio Spherical to Horizontal	.803	.840
Percent Absorption		16.8
Percent Light thrown below Equator	50.9	59.2
Percent Light thrown above Equator	49.1	40.8
Angle of Maximum Candle Power	0°	-60°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.497
Watts in Lamp	55.6	55.7
Watts per Mean Spherical Candle Power	.492	5.53
Watts per Mean Horizontal Candle Power	.394	4.64

Number of Test 191

_____ Circle Shows Rated Candle Power.

_____ Circle Shows Mean Spherical Candle Power.

_____ Circle shows Mean Horizontal Candle Power.

Lamp Used G.E. 112 v. 16 CP.

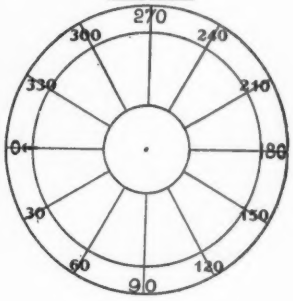
Globe Used HOLOPHANE TULIP #2250

Standard Used AGED INCANDESCENT

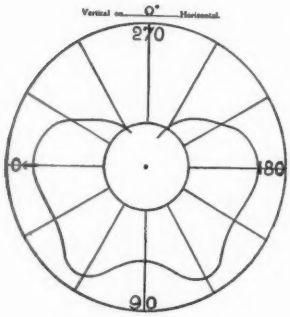
Date of Test JUNE 2, 1900

Remarks _____

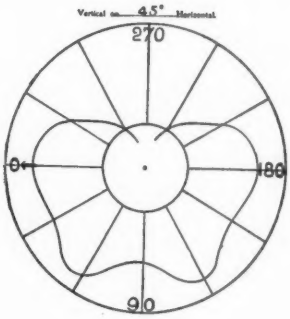
Horizontal Distribution.



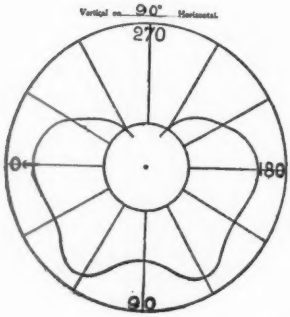
Vertical on 0° Horizontal.



Vertical on 45° Horizontal.



Vertical on 90° Horizontal.



Vertical on 135° Horizontal.

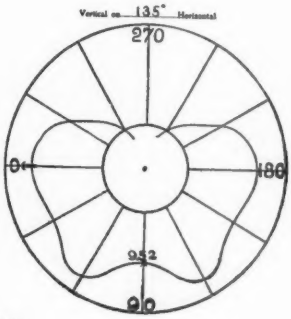
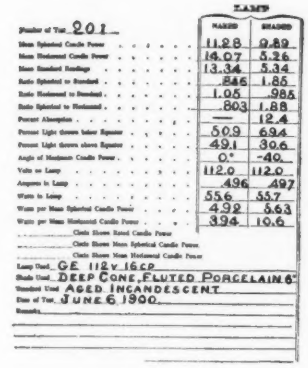
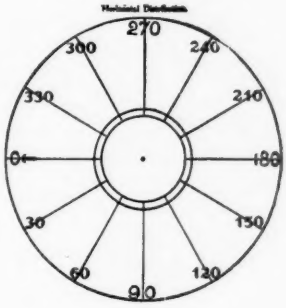


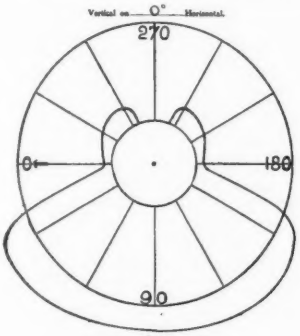
PLATE XVI.

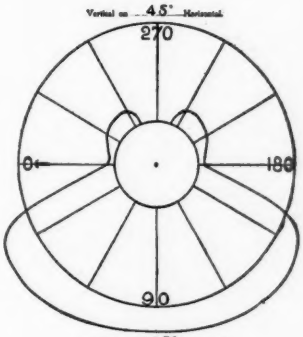


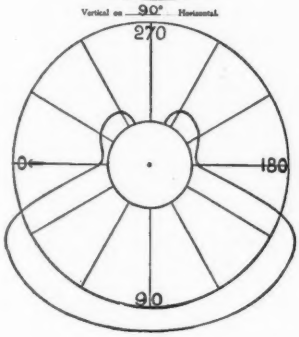
LAMP	NAKED	SHADED
Mean Spherical Candle Power	11.28	9.89
Mean Horizontal Candle Power	14.07	5.26
Mean Standard Readings	13.34	5.34
Ratio Spherical to Standard	.846	1.85
Ratio Horizontal to Standard	1.05	.985
Ratio Spherical to Horizontal	.803	1.88
Percent Absorption	——	12.4
Percent Light thrown below Equator	50.9	69.4
Percent Light thrown above Equator	49.1	30.6
Angle of Maximum Candle Power	0°	-40
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.497
Watts in Lamp	55.6	55.7
Watts per Mean Spherical Candle Power	4.92	5.63
Watts per Mean Horizontal Candle Power	3.94	10.6
——— Circle Shows Rated Candle Power		
——— Circle Shows Mean Spherical Candle Power		
——— Circle Shows Mean Horizontal Candle Power		

Lamp Used GE 112 V 16 CP
Shade Used DEEP CONE, FLUTED PORCELAIN 6"
Standard Used AGED INCANDESCENT
Date of Test JUNE 6 1900
Remarks









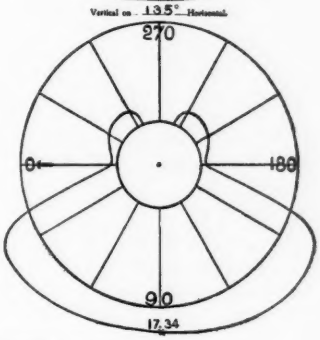
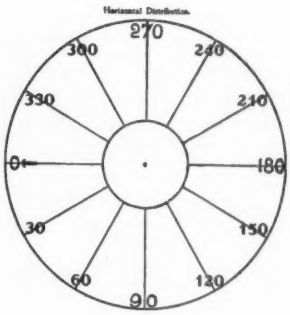
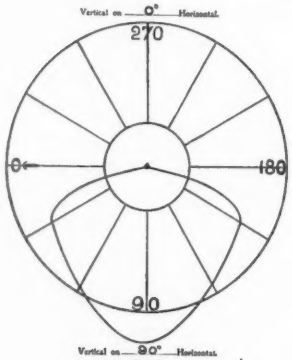
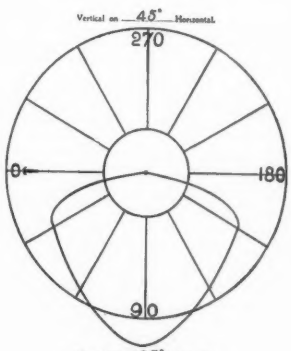


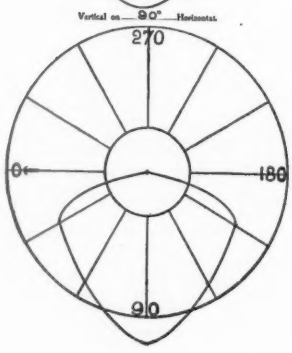
PLATE XVII.

Number of Test 211	LAMP	
	NAKED	SHADED
Mean Spherical Candle Power	1128	8.12
Mean Horizontal Candle Power	14.07	0.0
Mean Standard Readings	13.34	0.0
Ratio Spherical to Standard	.846	—
Ratio Horizontal to Standard	1.05	—
Ratio Spherical to Horizontal	.803	—
Percent Absorption	—	28.1
Percent Light thrown below Equator	50.9	100.
Percent Light thrown above Equator	49.1	0.0
Angle of Maximum Candle Power	0°	-90°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.496	.497
Watts in Lamp	55.6	55.7
Watts per Mean Spherical Candle Power	.492	6.86
Watts per Mean Horizontal Candle Power	.394	—
_____ Circle Shows Rated Candle Power.		
_____ Circle Shows Mean Spherical Candle Power.		
_____ Circle Shows Mean Horizontal Candle Power.		
Lamp Used G.E. 112 v 16 cp		
Shade Used ENAMELLED TIN DEEP CONE 8"		
Standard Used AGED INCANDESCENT		
Date of Test JUNE 7 1900		
Remarks _____		









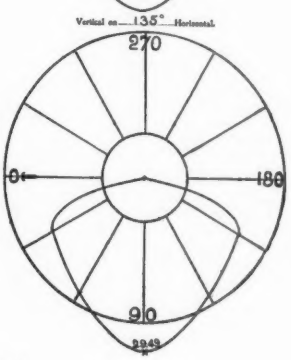
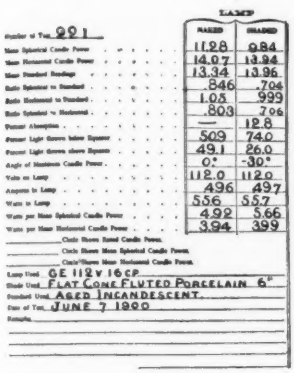


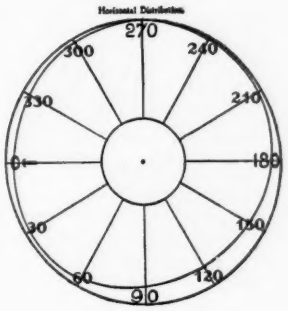
PLATE XVIII.

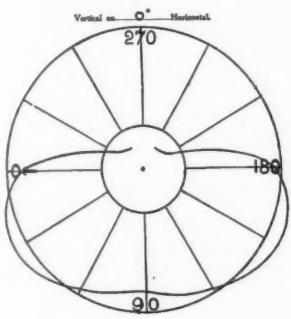


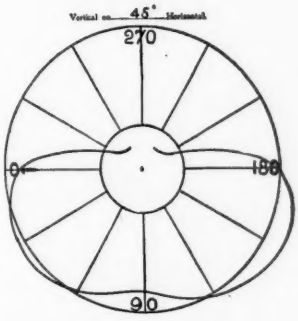
Number of Test 991	LAMP	
	BARED	SHADED
Mean Spherical Candle Power	11.28	9.84
Mean Horizontal Candle Power	14.07	13.94
Mean Standard Readings	13.34	13.96
Ratio Spherical to Standard	.846	.704
Ratio Horizontal to Standard	1.05	.999
Ratio Spherical to Horizontal	.803	.706
Percent Absorption	—	12.8
Percent Light thrown below Equator	50.9	74.0
Percent Light thrown above Equator	49.1	26.0
Angle of Maximum Candle Power	0°	-30°
Volts on Lamp	112.0	112.0
Amperes in Lamp	4.96	4.97
Watts in Lamp	556	557
Watts per Mean Spherical Candle Power	4.92	5.66
Watts per Mean Horizontal Candle Power	3.94	3.99

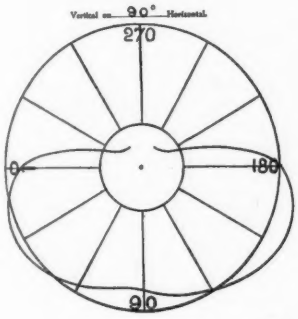
_____ Circle Shows Bared Candle Power.
_____ Circle Shows Mean Spherical Candle Power.
_____ Circle Shows Mean Horizontal Candle Power.

Lamp Used GE 112 V 16 CP
Shade Used FLAT CONE FLUTED PORCELAIN 6"
Standard Used AGED INCANDESCENT.
Date of Test JUNE 7 1900
Remarks









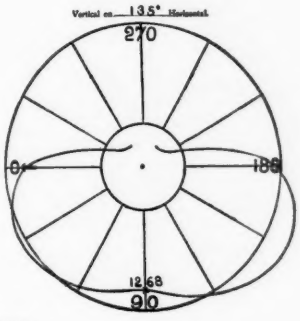
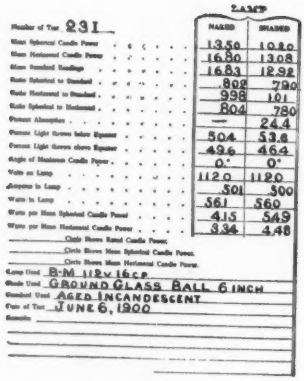


PLATE XIX.

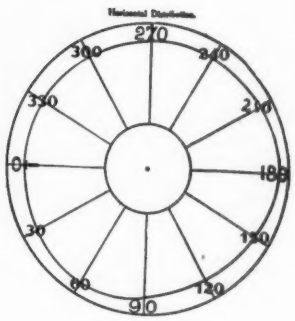


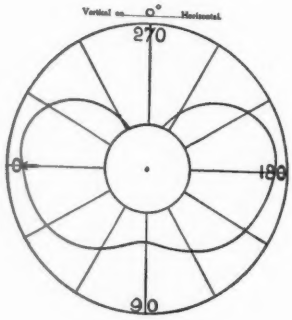
Number of Test 231

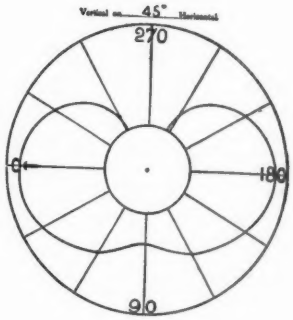
LAMP	
NAKED	SHADED
Mean Spherical Candle Power	1350	1080
Mean Horizontal Candle Power	1680	1308
Mean Standard Readings	1683	1292
Ratio Spherical to Standard	802	790
Ratio Horizontal to Standard	998	101
Ratio Spherical to Horizontal	804	780
Percent Absorption	—	24.4
Percent Light thrown below Equator	504	538
Percent Light thrown above Equator	496	464
Angle of Maximum Candle Power	0°	0°
Volts on Lamp	1120	1120
Amperes in Lamp	.501	.500
Watts in Lamp	561	560
Watts per Mean Spherical Candle Power	415	549
Watts per Mean Horizontal Candle Power	334	448

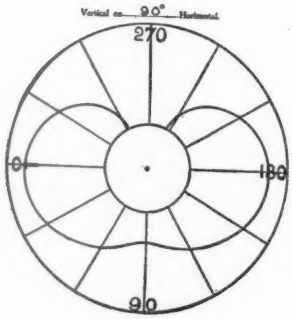
_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power.
_____ Circle Shows Mean Horizontal Candle Power.

Lamp Used B-M 112v 16cp
Globe Used GROUND GLASS BALL 6 INCH
Standard Used AGED INCANDESCENT
Date of Test JUNE 6, 1900
Remarks









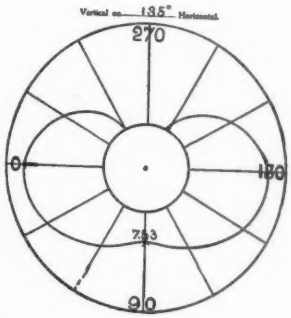


PLATE XX.

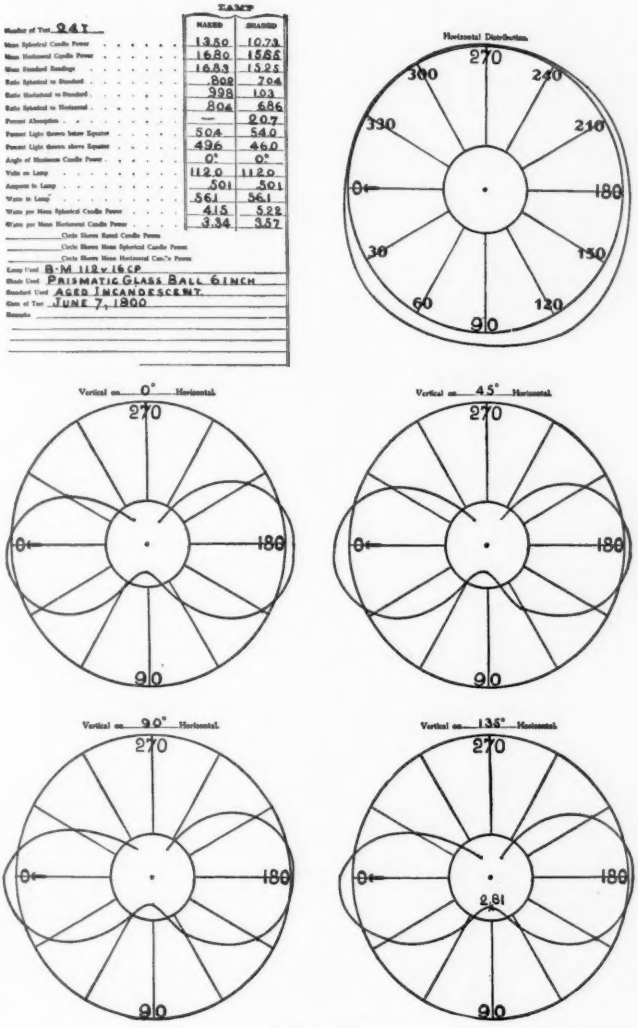
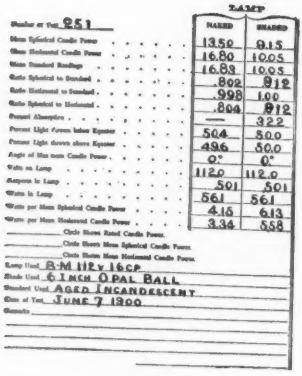

LAMP
Shades of Test 941
NAKED
SHADED
Mean Spherical Candle Power 1350 1073
Mean Horizontal Candle Power 1680 1585
Mean Standard Readings 1683 1525
Ratio Spherical to Standard 808 704
Ratio Horizontal to Standard 998 103
Ratio Spherical to Horizontal 804 686
Percent Absorption — 207
Percent Light thrown below Equator 504 540
Percent Light thrown above Equator 496 460
Angle of Maximum Candle Power 0° 0°
Volts on Lamp 112.0 112.0
Amperes in Lamp .501 .501
Watts in Lamp 56.1 56.1
Watts per Mean Spherical Candle Power 4.15 5.28
Watts per Mean Horizontal Candle Power 3.34 3.57
Circle Shows Rated Candle Power
Circle Shows Mean Spherical Candle Power
Circle Shows Mean Horizontal Can.'s Power
Lamp Used B-M 112v 16CP
Shade Used PRISMATIC GLASS BALL 6 INCH
Standard Used AGED INCANDESCENT
Date of Test JUNE 7, 1900
Remarks
Horizontal Distribution
270
300
240
330
210
0
180
30
150
60
120
90
Vertical on 0° Horizontal.
270
0
180
90
Vertical on 45° Horizontal.
270
0
180
90
Vertical on 90° Horizontal.
270
0
180
90
Vertical on 135° Horizontal.
270
0
180
2.81
90

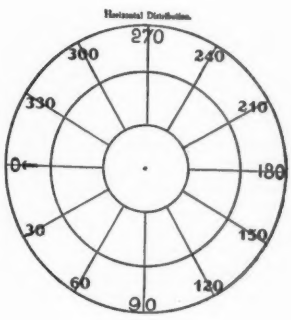
PLATE XXI.

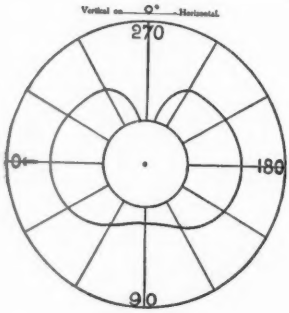


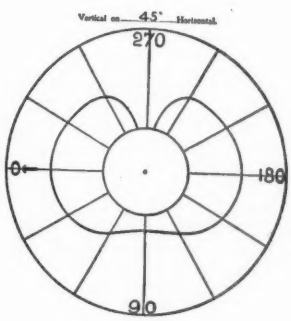
Number of Test 251	LAMP NAKED	LAMP SHADED
Mean Spherical Candle Power	13.50	9.15
Mean Horizontal Candle Power	16.80	10.05
Mean Standard Readings	16.83	10.05
Ratio Spherical to Standard	.802	.912
Ratio Horizontal to Standard	.998	1.00
Ratio Spherical to Horizontal	.804	.912
Percent Absorption	—	32.2
Percent Light Thrown below Equator	50.4	50.0
Percent Light thrown above Equator	49.6	50.0
Angle of Max mum Candle Power	0°	0°
Volts on Lamp	112.0	112.0
Amperes in Lamp	.501	.501
Watts in Lamp	56.1	56.1
Watts per Mean Spherical Candle Power	4.15	6.13
Watts per Mean Horizontal Candle Power	3.34	5.58

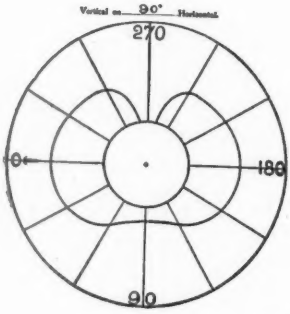
_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power.
_____ Circle Shows Mean Horizontal Candle Power.

Lamp Used B.M. 112 v. 16 cp.
Shade Used 6 INCH OPAL BALL
Standard Used AGED INCANDESCENT
Date of Test JUNE 7 1900
Remarks









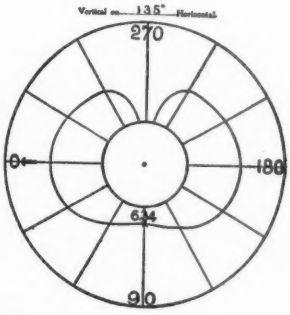


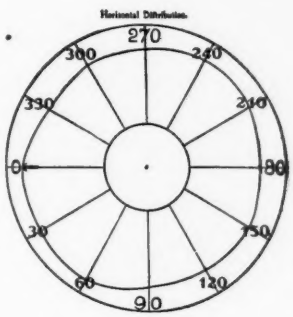
PLATE XXII.

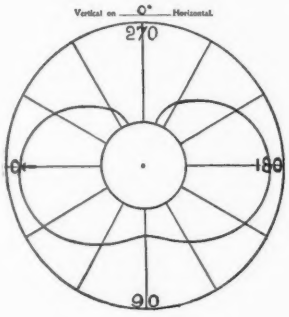
LAMP

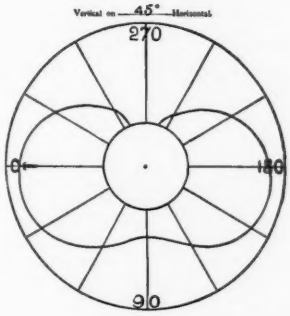
Number of Test 961	NAKED	SHADED
Mean Spherical Candle Power	1350	1038
Mean Horizontal Candle Power	1680	1250
Mean Standard Readings	1683	1320
Ratio Spherical to Standard	.802	.787
Ratio Horizontal to Standard	.998	.948
Ratio Spherical to Horizontal	.804	.831
Percent Absorption	—	23.0
Percent Light thrown below Equator	50.4	54.5
Percent Light thrown above Equator	49.6	45.5
Angle of Maximum Candle Power	0°	10°
Volts on Lamp	112.0	112.0
Amperes to Lamp	.501	.502
Watts to Lamp	56.1	56.2
Watts per Mean Spherical Candle Power	4.15	5.42
Watts per Mean Horizontal Candle Power	3.34	4.50

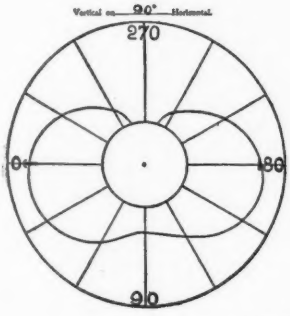
_____ Circle Shows Rated Candle Power.
_____ Circle Shows Mean Spherical Candle Power
_____ Circle Shows Mean Horizontal Candle Power.

Lamp Used B-M 112 v 16 cp
Shade Used OPALINE BALL SPIRAL FLUTINGS 6"
Standard Used AGED INCANDESCENT
Date of Test JUNE 8, 1900
Remarks









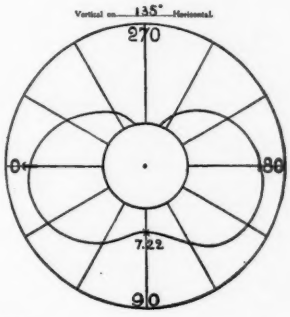


PLATE XXIII.

The absorption factors range from a minimum of 10 per cent. to a maximum of 33.5 per cent., in the cases of the large Holophane Stalactite (using the 50 candle-power lamp) and the McCreary Shade, respectively. The watts per mean spherical candle-power vary from a minimum of 5.22 to a maximum of 7.41 in the cases of the Prismatic Glass Ball and the McCreary Shade respectively.

The watts per maximum candle-power vary from a minimum of 1.30 to a maximum of 5.64 in the cases of the McCreary Shade and the Stalactite Prism respectively.

It is, however, manifestly unfair to make a direct comparison between a shade which, like the silvered minor A. E. G. lamp, aims simply to concentrate the light downward without diffusion, and one which, like the Opal Ball, aims simply to diffuse the light without changing its distribution materially; while, again, both these types should be separated from such shades as the Holophanes, which aim not only at redistribution, but at diffusion, and, moreover, at such thorough softening of the light as to render it possible to see objects comfortably, even when the light is directly in the field of view (as is perfectly possible with a 12-inch sphere containing a 100 candle-power light). Indeed, in one place recently fitted with these shades, there was a 16-inch sphere containing a 150 candle-power lamp surrounded by a circle of eight 8-inch spheres, each containing a 32 candle-power lamp, giving a maximum of 360 candle-power, allowing for absorption, concentrated in a space of about fifty square feet, and the lights nearly in the same plane. It was here found perfectly possible to view with comfort the detail of ornament directly behind this cluster.

The Holophanes, therefore, set themselves a more difficult problem than the great majority of shades tested, and one would hardly expect as great efficiency from them as from a pattern aiming at a less exalted mark. This, however, turns out contrary to expectation.

Another point to be considered is brought out by these tests as follows: If we take the Holophane, Class A, No. 3,354, and test it with a 32 candle lamp, we shall have an absorption of 14.6 per cent., while, if we test it with a 16 candle lamp we get an absorption of 12.2 per cent. Again, take the larger stalactite, No. 3,250. Testing with a 16 candle lamp at 112 volts, we find an absorption of 16.2 per cent. If we use this same lamp, and run it at 140 volts, thus getting a candle-power of (as it turned out) 37, we find the absorption has risen to 17.5 per cent., the distribution not being greatly changed.

This, I think, is because of the higher refrangibility of the rays given out. But if we get this same candle-power by using a larger lamp, as is shown in column 4 A of the table, we get an absorption of but 10 per cent. Accordingly, as I have found this rule to hold in other cases as well as those here mentioned, it seems clear that for each size of Holophane shade there is a particular sized lamp which will turn out to be best suited to that shade.

If, then, we tabulate the tests upon the Holophane type of shades, we shall have the following table, giving as a mean percentage of absorption 13.2 per cent. :

	Number of shade.	Per cent. absorption.	Effi. in terms of watts per mean sph. c. p.
1	3,551.	13.8%	86.3
2	3,354 (16 candle-power.)	12.2%	89.3
3	3,354 (32 candle-power.)	14.6%	85.6
4	3,250 (16 candle power.)	16.1%	84.1
5	3,250 (same lamp, run 30 volts high.)	17.5%	77.0
6	3,250 (50 candle-power.)	10.0%	90.2
7	3,150 (old style.)	16.8%	83.4
8	3,150 (new style.)	10.8%	89.4
9	3,105.	12.1%	87.8
10	2,250.	10.8%	89.4
11	2,251.	10.1%	89.3

The above value, however, includes two items which could be with perfect justice discarded, namely, Nos. 5 and 7, the former because no one would ever dream of running a lamp 30 volts high, and the latter because it represents an obsolete form which was tested only as a matter of historical interest. Discarding, then, these two values, the mean result remaining is 12.3 per cent. This, again, might with good show of reason be reduced by further omitting Nos. 3 and 4, since, as we have seen, if this type of shade is used under strictly the best conditions, the size of shade and lamp will be mutually adjusted. If this modification be made, we reach a final value of 11.4 per cent. as the absorption. As, however, it is not probable that in

many cases such an amount of care would be used, we will take both values into consideration. We shall find that, except for the satisfaction of being able to claim an additional 0.9 per cent. for this type of shade, nothing is altered. The only shade which appears with a less absorption factor is the "m" Prismatic Tulip, with a value of 10.1 per cent. The two fluted Porcelain Cones are the only shades which approach the above values, having one an absorption of 12.4 per cent., and the other an absorption of 12.8 per cent. These, however, are both simply reflectors, and make no claim to diffusion or softening of glare, while the "m" Prismatic Tulip is also in no sense a substitute for the Holophane, and is hardly more than a clear glass shade with ornamental cutting. Aside from these three, no other shade comes within 10 per cent. of the Holophanes, the nearest approach being that of the Prismatic Ball, with a value of 20.7 per cent. The McCreary shade stands at the other end of the list, its absorption being 33.5 per cent.; it has close competitors, however, in the Stalactite Prism, the Opal Ball, and the Tin Cone, with absorptions of 30.8 per cent., 32.2 per cent., and 28.1 per cent. respectively.

We may compare efficiencies in the line of watts per mean spherical candle-power, but since the various test lamps used do not have the same values for this quantity, we cannot compare the shades directly. We may, however, determine for each shade the value of

$$\frac{\text{Watts per mean spherical candle power (unshaded lamp)}}{\text{Watts per mean spherical candle power (shaded lamp)}}$$

when the most efficient shade will, of course, be that in which this quantity most nearly approaches unity.

Applying this criterion, and figuring the Holophanes as before, we get values 86.6 per cent., 87.9 per cent., and 88.8 per cent. respectively. Again, agreeing that the first value is not properly to be used, we find that it makes no difference which of the other two we see fit to use, which, of course, is to be expected, as this is only another way of expressing the former results. The "m" Prismatic Tulip has a value of 89.3, and the two Porcelain Cones of 87.8 per cent. and 87.0 per cent. respectively.

If we consider further the watts per maximum candle-power thrown in any direction, we find, of course, that the pure reflectors take first rank. The McCreary shade leads on the face of things, followed rather closely by the A. E. G. silvered lamp, and at a somewhat greater distance by the Enamel Tin Cone. I question, however,

whether this is correct, since the A. E. G. lamp was not really new, but had been burned, off and on, for some time, probably for a hundred or more hours, so that, although it furnished legitimate data for determining the effect of silvering a naked lamp of the same type, it is not probably correct to compare it with the other shades fitted with newer and more carefully kept lamps.

Thus far, nothing has been said upon the very important subject of illumination produced upon surfaces such as the floor, drawing-tables, etc., or of the general distribution of light throughout the room. Neither has the quality of the illumination, nor its effect upon the worker or occupant of the room been considered. These matters are reserved for further investigation, and it is hoped will form a second part of the present article.

From the results obtained so far in the investigation, it is my opinion that the Holophane type of shade is very greatly superior in general results to any other investigated.

ROGERS LABORATORY OF PHYSICS,
June, 1900.

RESULTS OF TESTS MADE IN THE ENGINEERING LABORATORIES.

XII.

Received June 6, 1900.

Applied Mechanics.

Tests on Boiler Tube Columns.

These columns were old boiler tubes taken from worn-out boilers. They were tested in the Emery machine. The ends of the tubes were left in the same condition in which they are used in building, the ends being sawed off approximately square. Thirteen tests were made of old tubes, 4″ diameter, and 6, 7 and 8 feet long; and six tests were made on new tubes of the same sizes to find the loss of strength of the tubes which had been in use. Four tests were made on old tubes, in which the tubes were heated in a charcoal fire to get the loss of strength due to heat. In each of these four tests the tube was placed in the machine and a small load applied. The fire was then built around the tube in a V-shaped receptacle made of steel boiler plate, and furnished with an air blast through tuyères at the bottom. The length of this receptacle was about 5 feet.

BOILER TUBE COLUMNS.

Summary of Tests.

Number of test.	Length of column. (Ins.)	Outside diameter. (Ins.)	Thickness. (Ins.)	Gauge length. (Ins.)	Maximum load. (Lbs.)	Area of cross section. (Sq. in.)	Maximum load per sq. in. (Lbs.)	Compression. Modulus of elasticity.	$\frac{l}{\rho}$, or ratio of length to radius of gyration.	Remarks.
1	72.0	4.00	0.13	30	40,000	1.58	25,300	30,400,000	52.6	
2	71.9	4.00	0.15	30	50,000	1.82	27,500	28,400,000	52.8	Tests Nos. 1–13 inclusive, made on old tubes taken from boilers.
3	72.0	3.99	0.13	30	46,000	1.57	29,300	27,900,000	52.7	
4	72.0	4.01	0.14	30	36,000	1.70	21,200	26,300,000	52.6	
5	72.1	3.98	0.15	30	47,000	1.80	26,100	26,500,000	53.2	
6	72.0	3.97	0.13	30	34,600	1.57	22,000	29,300,000	53.0	
7	83.9	4.00	0.15	70	42,800	1.82	23,500	27,700,000	61.6	
8	84.1	4.00	0.15	70	37,900	1.82	20,800	27,800,000	61.7	
9	96.2	4.00	0.18	70	36,900	2.16	17,100	23,700,000	71.2	
10	96.0	3.98	0.15	70	43,200	1.80	24,000	29,200,000	70.9	
11	96.0	3.99	0.14	70	35,000	1.69	20,700	27,000,000	70.5	
12	96.2	4.00	0.14	70	36,800	1.70	21,600	27,800,000	70.4	
13	96.0	4.00	0.16	70	43,000	1.93	22,300	25,300,000	70.7	
14	72.0	4.00	0.14	30	64,800	1.70	38,100	30,800,000	52.7	
15	72.0	3.99	0.12	30	55,600	1.46	38,100	30,400,000	52.6	
16	84.0	3.98	0.15	70	58,700	1.80	32,600	28,200,000	62.0	Tests Nos. 14–19 inclusive, made on new tubes.
17	84.0	3.98	0.15	70	62,200	1.80	34,600	27,500,000	62.0	
18	96.0	3.99	0.14	70	56,000	1.69	33,200	26,600,000	70.5	
19	96.1	4.02	0.15	70	57,600	1.82	31,600	26,700,000	70.2	
20	83.9	4.00	0.16	..	34,000	1.93	17,600	.....	61.8	Heated to dull cherry-red, through a length of 4 feet at middle of column.
21	84.1	4.00	0.16	..	7,500	1.93	3,890	.....	61.9	Heated to a bright red through a length of about 4 feet at middle of column.
22	84.5	3.99	0.14	..	4,500	1.75	2,570	.....	62.1	Heated to bright red on top, and nearly white heat on bottom through a length of about 4 feet at middle of column.
23	96.0	4.00	0.13	..	13,300	1.58	8,420	.....	70.6	Heated to a bright red on bottom, and a dull red on top through a length of about 4 feet at middle of column.
										Tests Nos. 20–23 inclusive, made on old tubes taken from boilers.

TRANSVERSE TESTS UPON HARD PINE BEAMS.

Number of test.	Width and depth of specimen. (Ins.)	Distance between supports in feet and inches.	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflections for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of Failure.	Remarks.	Manner of Loading.
623	4 x 12	15—0	500— 4,500	.5498	1,530,000	9,015	275	4,290	145	Broke by tension.		At centre.
624	4 x 12⅛	15—0	500— 6,500	.6785	1,760,000	17,960	260	8,140	279	Broke by tension.		At centre.
625	3⅞ x 11⅞	15—0	500— 6,500	.6789	1,980,000	21,100	284	10,500	348	Broke by tension.		At centre.
626	4 x 12	15—0	2,000— 5,000	.2973	2,130,000	20,260	258	9,560	321	Broke by tension followed by shear.		At centre.
627	4 x 12	15—0	500— 4,500	.7597	1,110,000	6,210	246	2,970	101	Broke by shearing.		At centre.
628	6 x 8	8—5½	1,000— 7,000	.2370	2,170,000	29,685	164	11,800	467	Broke by shearing.		At centre.
629	6⅛ x 8⅛	8—0	1,000— 7,000	.1536	2,130,000	37,060	239	11,400	506	Broke by tension.		At centre.
630	5⅞ x 7⅞	8—0	1,000— 5,000	.1810	1,830,000	24,085	139.5	10,100	410	Broke by tension.		At centre.
630a	6 x 6	12—0	500— 3,500	.7847	2,200,000	13,320	169	13,600	285			At centre.
631	6 x 12	13—0	500— 6,500	.2910	1,890,000	31,110	330	8,470	328	Broke by tension followed by crushing and shearing.		At centre.
632	7⅛ x 7⅛	12—0	1,000— 5,000	.5950	1,390,000	10,180	180	4,750	129	Broke by tension.	Old stock.	At centre.
633	6 x 12	14—0	1,000—11,000	.5594	2,040,000	29,010	376	8,520	306	Broke by shearing.		At centre.
634	6 x 12	14—0	1,000—11,000	.5192	2,200,000	33,390	412	9,800	352	Broke by shearing.		At centre.
635	6 x 12	14—6	500—15,500	.9997	1,910,000	29,210	365	8,880	308	Broke by tension.		At centre.
636	6 x 12	14—0	1,000—11,000	.5839	1,960,000	30,210	303	8,850	318	Broke by crushing.		At centre.
637	6 x 12	14—0	500—15,500	.9545	1,800,000	29,910	325	8,770	315	Broke by crushing.		At centre.
639	6 x 12⅛	16—6	1,000— 5,000	.6803	1,090,000	14,110	375	4,870	150	Broke by tension.		At centre.
640	6 x 12	11—1½	1,000—17,000	.5320	1,710,000	26,795	295	6,220	282	Broke by shearing.		At centre.
641	6 x 12	11—0	1,000—17,000	.4906	1,810,000	31,630	284	7,280	333	Broke by shearing.		At centre.
642	6 x 12	11—0	1,000— 9,000	.4781	2,090,000	39,150	368	9,010	412	Broke by shearing.		At centre.
643	6⅛ x 12⅛	11—0	1,000—13,000	.3774	1,700,000	37,450	328	8,360	383	Broke by tension.		At centre.
644	6⅛ x 12	9—0	1,000—13,000	.2361	1,510,000	42,640	238	7,850	437	Broke by tension.		At centre.
645	6⅛ x 12⅛	10—0	1,000—13,000	.2741	1,680,000	40,350	267	7,930	406	Broke by shearing.		At centre.
646	5⅛ x 11⅛	15—0	1,000— 9,000	.5331	2,170,000	30,150	433	9,780	323	Broke by shearing.		At centre.
647	6 x 12	17—0	1,000— 9,000	.8368	1,960,000	20,650	497	7,400	220	Broke by tension.		At centre.
648	5⅛ x 11⅛	15—0	1,000—11,000	.6834	2,110,000	24,400	457	7,850	263	Broke by shearing.		At centre.
651	8⅛ x 10⅛	14—0	1,000— 9,000	.4325	2,180,000	35,580	460	7,140	324	Broke by tension.		At two points.
652	6 x 8	14—0	2,000— 8,000	1.5452	1,500,000	10,775	225	7,150	172	Broke by tension.		At centre.
653	10⅛ x 8⅛	15—0	1,000— 7,000	.6067	2,130,000	27,155	470	7,100	245	Broke by tension.		At two points.
654	8⅛ x 6⅛	14—0	500— 3,500	.8006	1,900,000	14,730	350	10,430	204	Broke by tension.		At centre.
656	6 x 8	14—0	2,000— 6,000	1.2912	1,180,000	7,445	295	4,980	121	Broke by tension at knot.		At centre.
658	8⅛ x 6⅛	14—0	1,000— 3,000	.7117	1,650,000	9,020	310	7,340	136	Broke by tension at small knot.		At centre.
667	8 x 10	15—0	1,000— 9,000	.5302	2,342,000	39,130	440	8,880	371	Broke by tension.		At two points.
668	6⅛ x 8⅛	14—0	500— 5,500	.9075	1,987,000	16,675	205	10,450	254	Broke by tension.		At centre.
669	8 x 6	13—0	1,000— 5,000	.9176	2,393,000	14,500	210	11,860	230	Broke by tension.		At centre.
671	10⅛ x 8⅛	15—0	1,000— 6,000	.4091	2,795,000	38,555	415	10,470	355	Broke by tension.		At two points.
676	8 x 10	15—0	1,000— 5,000	.5334	1,367,000	16,105	460	5,510	155	Broke by tension.		At centre.

Note. — In beams loaded at two points, the load was equally divided between two points equidistant from the centre, and ⅓ of the length of the span apart.

TRANSVERSE TESTS UPON SPRUCE BEAMS.

Number of test.	Width and depth of specimen. (Ins.)	Distance between supports. (Feet and inches.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflections for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of Failure.	Remarks.	Manner of Loading.
655	8 x 10	14—0	1,000—7,000	.4788	1,580,000	24,040	245	5,090	228	Failed by shearing.		At two points.
657	9⅞ x 8	14—0	1,000—7,000	.8586	1,400,000	13,430	230	3,620	130	Failed by tension.		At two points.
659	10 x 7⅞	15—0	2,000—6,000	.6747	1,510,000	18,680	275	5,480	181	Failed by tension.		At two points.
660	6½ x 8	14—0	1,000—6,000	1.3497	1,400,000	9,400	240	6,120	148	Failed by tension.		At centre.
661	8 x 10	15—0	1,000—5,000	.5761	1,080,000	18,230	280	4,150	174	Failed by tension.		At two points.
662	8 x 6	14—0	2,000—4,000	.9237	1,500,000	6,570	170	5,820	105	Failed by tension.		At centre.
663	8 x 10	15—0	1,000—3,000	.3280	947,000	12,030	255	2,750	115	Failed by tension.	Had flaw on tension side.	At two points.
664	6 x 8	14—0	2,000—4,000	.5877	1,313,000	7,595	155	5,030	124	Failed by tension.		At centre.
665	9⅛ x 7¾	16—0	500—4,500	.9656	1,376,000	13,800	300	4,600	140	Failed by tension.		At two points.
666	8 x 6	14—0	1,000—4,000	1.4377	1,432,000	7,250	150	6,400	116	Failed by tension.		At centre.
670	8 x 5¾	13—0	1,000—4,000	1.0478	1,786,000	8,920	180	7,970	148	Failed by tension.		At centre.
672	5¾ x 8	13—0	1,000—4,000	.7583	1,275,000	7,920	160	5,090	132	Failed by tension.		At centre.
684	3⅝ x 12⅛	19—0	1,000—2,000	.2938	1,509,000	8,157	201	5,120	138	Failed by tension.		At centre.
685	3¾ x 12	14—0	500—4,500	.5555	1,317,000	12,330	189	5,800	209	Failed by tension.		At centre.
686	3¾ x 12	19—0	1,000—3,000	.5860	1,415,000	9,157	200	5,860	136	Failed by tension.		At centre.
687	3¾ x 12	21—0	500—4,500	.3014	1,178,000	10,415	115	3,840	176	Failed by tension.	Part of No. 685.	At centre.
688	3⅝ x 12⅛	19—0	1,000—2,000	.3769	1,177,000	5,357	195	3,396	92	Failed by tension.		At centre.
689	4 x 12	8—0	1,000—4,000	.1014	947,000	15,660	75	3,915	245	Failed by tension.		At centre.

Note. — In beams loaded at two points, the load was equally divided between two points equidistant from the centre, and ⅓ of the length of the span apart.

TRANSVERSE TESTS UPON WHITE PINE.

Number of test.	Width and depth of specimen. (Ins.)	Distance between supports. (Feet and inches.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflections for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of Failure.	Manner of Loading.
649	15⅛ x 15	20—0	1,000—21,000	.8763	1,450,000	64,702	953	5,920	206	Failed by tension.	At two points, 1 foot each side of centre.
650	17½ x 16¾	20—0	5,000—25,000	.7444	1,129,000	65,070	1,125	4,398	172	Failed by longitudinal shearing.	At two points, 1 foot each side of centre.
677	9 x 15¾	18—0	1,000—13,000	.7596	1,130,000	33,155	510	4,850	178	Failed by tension.	At centre.
678	9¼ x 16	18—0	1,000— 9,000	.4541	1,172,000	37,830	560	5,220	195	Failed by tension followed by shearing.	At centre.
679	6¼ x 15	14—0	1,000— 7,000	.2595	1,250,000	22,085	300	3,830	172	Failed by tension.	At centre.
680	8 x 16	12—0	1,000— 5,000	.1095	833,000	17,260	315	1,840	103	Failed by tension.	At centre.
681	10¾ x 19¾	15—0	1,000— 7,000	.1104	958,000	37,155	674	2,410	134	Failed by tension.	At centre.
682	8¼ x 14	15—0	1,000—11,000	.4278	1,461,000	47,956	443	7,810	305	Failed by tension.	At centre.
683*a*	8⅛ x 19	10—0	1,000—21,000	.1389	1,050,000	72,200	455	4,180	333	Failed by shearing.	At centre.

Notes. — Beams 649 and 650 were from an old market on State Street, Boston. Beams had been in use at least seventy-five years. Sticks were hand hewn.
Beams 677 to 683*a* inclusive, were parts of an old railway bridge truss from Bellows Falls, Vermont.

TORSION TESTS ON COLD ROLLED STEEL SHAFTING 1⅛" DIAMETER. (From Jones & Laughlin's.)

Number of test.	Diameter of cross section. (Ins.)	Distance between jaws. (Ins.)	Gauged length. (Ins.)	Elastic limit. (In. Lbs.)	Outside fiber stress at elastic limit. (Lbs. per sq. in.)	Maximum twisting moment. (In. Lbs.)	Apparent outside fiber stress as calculated from maximum twisting moment. (Lbs. per sq. in.)	Limits of loads for calculating shearing modulus of elasticity. (In. Lbs.)	Angle of twist for difference of loads used in calculating shearing modulus of elasticity.	Shearing modulus of elasticity. (Lbs. per sq. in.)	Number of turns between jaws at fracture.	Turns per foot between jaws at fracture.
13	1.687	69.4	50	27,000	28,610	69,030	73,110	1,800—18,000	4°—57′— 5″	11,770,000	10.76	1.85
14	1.687	57.1	43	29,700	31,470	70,930	75,110	23,400—28,800	1°—37′—53″	11,400,000	8.30	1.70
15	1.688	72.0	50	28,800	30,510	69,030	73,110	1,800— 5,400	1°— 6′— 5″	11,760,000	11.28	1.88
16	1.685	61.9	40	31,500	33,590	71,100	75,840	1,800— 9,000	1°—44′—15″	12,030,000	9.37	1.81
17	1.690	72.9	50	27,900	29,430	69,480	73,300	3,600— 9,000	1°—37′—36″	11,880,000	6.33	1.04
18	1.686	73.4	50	29,700	31,790	65,340	69,930	1,800— 7,200	1°—38′—35″	11,990,000	13.16	2.18
19	1.690	71.3	50	31,500	33,330	73,225	76,170	1,800— 9,000	2°—12′—28″	11,660,000	8.25	1.39
20	1.687	71.4	50	29,700	31,560	71,100	75,560	1,800—10,800	1°—46′—55″	11,690,000	9.40	1.58
21	1.687	63.6	50	27,900	29,550	69,480	73,600	1,800— 9,000	2°—10′—10″	11,930,000	10.43	1.97
22	1.690	70.83	50	.....	.....	64,440	67,980	1,800— 7,200	1°—39′— 5″	11,680,000	14.70	2.49
23	1.684	70.97	50	26,100	27,840	65,970	70,370	3,600—10,800	2°—11′— 6″	11,960,000	13.85	2.35
24	1.686	59.63	40	28,800	30,720	65,250	69,580	1,800— 7,200	1°—18′—15″	12,020,000	8.05	1.13
25	1.685	57.38	40	27,900	29,760	71,640	76,400	1,800— 7,200	1°—19′—35″	11,820,000	9.72	2.05
26	1.686	71.50	50	29,700	31,550	72,720	77,290	1,800— 9,000	2°—11′—10″	11,900,000	11.66	1.98

TORSION TESTS ON REFINED IRON 1¼" DIAMETER.

Number of test.	Diameter of cross section. (Ins.)	Distance between jaws. (Ins.)	Gauged length. (Ins.)	Elastic limit. (Ins. Lbs.)	Outside fiber stress at elastic limit. (Lbs. per sq. in.)	Maximum twisting moment. (Ins. Lbs.)	Apparent outside fiber stress as calculated from maximum twisting moment. (Lbs. per sq. in.)	Limits of loads for calculating shearing modulus of elasticity. (In. Lbs.)	Angle of twist for difference of loads used in calculating modulus of elasticity.	Shearing modulus of elasticity. (Lbs. per sq. in.)	Number of turns between jaws at fracture.	Turns per foot between jaws at fracture.
1	1.78	63.38	40	19,800	17,880	64,620	58,340	3,600—19,800	3°—24′— 0″	11,080,000	7.48	1.42
2	1.74	58.38	40	19,800	19,140	60,210	58,220	3,600—19,800	4°— 2′—15″	10,220,000	6.90	1.42
3	1.74	57.50	40	16,200	15,660	55,080	53,260	1,800—18,000	3°—36′—35″	11,144,000	5.19	1.08
4	1.75	.....	40	16,200	15,660	59,400	57,440	3,600—14,400	2°—27′—34″	11,190,000	7.07	....
5	1.80	59.63	40	19,800	17,820	62,100	54,300	3,600—10,800	1°—24′—45″	11,350,000	7.07	1.42
6	1.77	57.75	40	16,200	14,630	50,220	45,350	1,800— 7,200	1°— 7′—35″	11,150,000	5.52	1.15
7	1.78	58.50	40	18,000	16,260	63,170	57,050	1,800— 7,200	1°— 4′—20″	11,710,000	5.43	1.11
8	1.77	60.13	40	16,200	14,630	59,940	54,130	1,800— 7,200	1°— 7′—30″	11,150,000	7.20	1.42
9	1.78	60.00	40	16,200	14,630	53,550	48,370	1,800— 7,200	1°— 6′— 2″	11,410,000	5.46	1.09
10	1.78	60.00	40	14,400	13,000	62,580	56,520	1,800— 9,000	1°—27′—25″	11,500,000	7.00	1.40
11	1.78	60.56	40	16,200	14,630	54,330	49,060	1,800— 9,000	1°—25′—55″	11,690,000	5.89	1.17
12	1.78	59.19	40	.....	.....	62,550	56,480	1,800— 9,000	1°—26′—46″	11,580,000	5.85	1.19
13	1.78	.....	40	14,400	13,000	62,640	56,570	1,800— 9,000	1°—25′—50″	11,700,000	5.96	....
14	1.79	59.12	40	14,400	12,790	64,620	57,380	1,800— 5,400	4°—50″	11,480,000	6.66	1.36

Tests on Building Brick.

This series of tests is a continuation of the series published in the *Technology Quarterly*, Vol. XII, p. 245. Two sets of tests were made on the same grade of bricks. In the first set the pressure was applied to the broad surfaces, and in the second set to the edges of the bricks, the idea being to find the difference in breaking strength, in pounds per square inch, in testing by the two ways. In all the tests the surfaces to which the pressures were applied were set in a thin layer of Portland cement, which was ground to a plane surface and allowed to set thoroughly before testing. The testing machine used was the 300,000 pounds Emery machine.

Tested on Broad Surface.

BAY STATE BRICK COMPANY. (Light hard.)

Number of Test.	Area of Cross Section. (Sq. in.)	Maximum Load. (Lbs.)	Maximum Load. (Lbs. per. sq. in.)	Amount of Water Absorbed. (Per cent.)
1	30.5	193,000	6,330	15.7
2	29.5	195,000	6,610	19.3
3	29.8	180,000	6,380	12.7
4	29.5	182,000	6,170	17.1
5	29.3	220,000	7,510	14.0
6	29.5	183,000	6,200	14.3
7	30.0	164,000	5,470	14.2
8	30.5	131,000	4,300	14.1
9	30.4	201,000	6,623	15.9
10	28.8	179,000	6,211	17.3
11	29.2	239,000	8,199	12.5
12	29.3	211,000	7,209	13.4
13	29.8	122,000	4,088	16.4
14	29.0	187,000	6,448	11.7
15	28.8	241,000	8,377	15.7
16	29.3	249,000	8,495	14.4
17	28.8	246,000	8,551	13.4
18	30.0	166,000	5,541	16.2
19	29.1	189,000	6,505	17.9
20	30.7	164,000	5,344	16.0
21	29.0	218,000	7,517	15.8
22	30.6	232,000	7,588	15.3
23	30.3	186,000	6,150	16.6
24	28.6	285,000	9,960	13.5
25	28.8	264,000	9,163	14.6
26	29.4	193,000	6,558	16.0
27	31.0	149,000	4,810	16.6
28	29.8	226,000	7,590	14.8
29	28.5	272,000	9,560	14.0
30	30.5	165,000	5,410	17.7
31	27.1	305,000	11,240	7.5
32	29.0	188,000	6,483	16.2

BAY STATE BRICK COMPANY. (Light hard.)—*Concluded.*

Number of Test.	Area of Cross Section. (Sq. in.)	Maximum Load. (Lbs.)	Maximum Load. (Lbs. per sq. in.)	Amount of Water Absorbed. (Per cent.)
33	29.0	148,000	5,100	16.8
34	30.0	185,000	6,180	14.1
35	30.9	189,000	6,110	15.9
36	29.0	254,000	8,760	14.0
37	28.8	243,000	8,443	15.8
38	29.5	247,000	8,390	14.0
39	29.5	250,000	8,490	12.6
40	30.2	221,000	7,320	16.1
41	29.5	225,000	7,627	16.6
42	30.5	171,000	5,579	17.0
43	29 5	285,000	9,627	13.3
44	30.0	220,000	7,340	16.7
45	29.0	160,000	5,520	15.6
46	28.8	285,000	9,906	13.5
47	28.9	277,000	9,570	13.2
48	29.3	180,000	6,140	16.2
49	28.4	102,000	3,587	19.3
50	31.2	187,000	5,993	17.6
51	27.9	269,000	9,654	14.0
52	30.0	250,000	6,333	15.8
53	30.2	168,000	5,521	18.2
54	29.0	187,000	6,440	17.6
55	29.5	180,000	6,102	16.8
56	29.3	212,000	7,239	13.9
57	30.0	227,000	7,574	14.2
58	29.7	220,000	7,397	17.0
59	28.3	246,000	8,677	12.2
60	29.0	171,000	5,888	16.9
61	28.1	305,000	10,870	10.4
62	28.3	305,000	10,785	9.5
63	28.3	200,000	7,070	17.0
64	28.5	234,000	8,282	14.0
65	30.0	118,000	3,940	17.6
66	29.8	137,000	4,600	16.8
67	29.3	163,000	5,570	13.4
68	28.1	210,000	7,480	18.8
69	29.3	164,000	5,600	18.2
70	27.9	216,000	7,750	15.0
71	30 7	185,000	6,030	8.9
Average			7,039	15.15
Maximum			11,240	19.3
Minimum			3,587	7.5

TESTED ON EDGE.

BAY STATE BRICK COMPANY. (Light hard.)

Number of Test.	Area of Cross Section. (Sq. in.)	Maximum Load. (Lbs.)	Maximum Load. (Lbs. per sq. in.)	Amount of Water Absorbed. (Per cent.)
1	18.0	92,000	5,110	16.6
2	18.0	71,000	3,940	16.1
3	16.8	80,000	4,770	16.0
4	18.3	137,000	7,490	14.9
5	19.0	91,000	4,790	15.2
6	17.7	148,000	8,350	10.0
7	18.1	120,000	6,615	15.8
8	18.5	80,000	4,317	17.1
9	18.5	102,000	5,504	15.9
10	19.1	78,000	4,088	14.9
11	18.0	63,000	3,500	9.4
12	18.1	117,000	6,449	13.2
13	18.6	89,000	4,245	15.5
14	18.6	113,000	6,068	10.5
15	17.7	98,000	5,540	12.0
16	18.5	109,000	5,892	11.0
17	18.6	111,000	5,968	10.5
18	17.7	112,000	6,327	7.4
19	17.6	160,000	9,106	10.6
20	18.0	101,000	5,630	11.6
21	19.6	96,000	4,903	11.8
22	18.4	140,000	7,609	9.1
23	18.1	103,000	5,700	11.3
24	17.7	143,000	8,100	10.3
25	17.3	111,000	6,280	11.6
26	18.0	132,000	7,333	11.3
27	18.0	140,000	7,778	10.0
28	18.1	133,000	7,220	10.5
29	18.4	91,000	4,940	10.0
30	17.5	146,000	8,350	8.3
31	18.0	98,000	5,440	11.7
32	18.0	141,000	7,833	14.2
33	18.6	98,000	5,257	16.0
34	18.8	72,000	3,829	12.0
35	18.9	73,000	3,854	16.8
36	19.3	74,000	3,325	17.7

BAY STATE BRICK COMPANY. (Light hard.) — *Concluded.*

Number of Test.	Area of Cross Section. (Sq. in.)	Maximum Load. (Lbs.)	Maximum Load. (Lbs. per sq. in.)	Amount of Water Absorbed. (Per cent.)
37	18.2	139,000	7,633	13.2
38	20.8	84,000	4,030	14.6
39	18.0	132,000	7,346	15.8
40	18.8	115,000	6,124	15.4
41	17.3	109,000	6,329	15.8
42	17.5	161,000	9,200	11.4
43	17.5	137,000	7,829	10.8
44	18.1	114,000	6,298	15.1
45	17.8	83,000	4,667	17.4
46	17.9	117,000	6,536	16.2
47	18.3	96,000	5,246	18.3
48	18.1	96,000	5,304	14.3
49	18.1	133,000	7,348	15.6
50	16.3	92,000	5,680	14.4
51	18.0	110,000	6,110	15.3
52	18.5	83,000	4,480	16.9
53	18.1	140,000	7,718	12.0
54	16.5	151,000	9,150	9.1
55	17.6	152,000	8,673	12.8
56	18.8	82,000	4,364	16.0
57	16.6	131,000	7,950	15.2
58	18.0	127,000	7,060	15.1
59	17.9	69,000	3,860	18.1
60	18.0	107,000	5,940	16.1
61	16.6	180,000	10,840	12.4
62	17.7	80,000	4,510	17.6
63	18.5	99,000	5,350	14.5
64	18.4	116,000	6,300	15.3
65	18.2	169,000	9,280	13.8
66	16 9	120,000	7,097	15.0
67	18.1	131,000	7,220	15.2
Average			6,241	13.67
Maximum			10,840	18.3
Minimum			3,325	7.4

Cement Tests.

The tests on cement in tension were made on briquettes of 1 square inch cross section, and the tests in compression on 2″ cubes. A description of the method of making these tests may be found in the *Technology Quarterly*, Vol. IX, 1896, p. 196. The sand used in making the sand tests was ground white quartz fine enough to pass through a sieve with 20 meshes per linear inch.

PORTLAND CEMENT. — NEAT CEMENT. (Tension.)

Brand.	Per cent. of Water Used in Mixing.	Time of Set.	Breaking Strength.
Saylor's.	24	24 hours.	300
"	24	"	311
"	24	"	312
"	24	"	266
"	24	"	276
"	24	"	268
"	24	"	278
"	24	2 days.	456
"	24	"	476
"	24	"	472
"	24	"	508
"	24	"	468
"	24	"	532
"	24	"	454
"	24	3 days.	512
"	24	"	524
"	24	"	516
"	24	"	540
"	24	"	625
"	24	"	535
"	24	4 days.	585
"	24	"	572
"	24	"	590
"	24	5 days.	660
"	24	"	750
"	24	"	756
"	24	7 days.	780
"	24	14 days.	782
"	24	"	797
"	24	"	800
"	24	"	900
"	24	"	820
"	24	"	780
"	24	17 days.	922
"	24	"	858
"	24	24 days.	980
"	24	"	1,040
"	24	"	1,100
"	24	30 days.	915
"	24	"	920
"	24	2 months.	950
"	24	"	1,055

PORTLAND CEMENT. — NEAT CEMENT. (Tension.) — *Concluded.*

Brand.	Per cent. of Water Used in Mixing.	Time of Set.	Breaking Strength.
Saylor's.	24	2 months.	1,100
"	24	"	1,010
"	24	"	1,080
"	24	3 months.	1,016
"	24	"	1,030
"	24	"	1,040
"	24	"	1,056
"	24	"	1,260
"	24	"	1,120
"	24	"	1,080
"	24	"	1,020
"	24	"	1,120
"	24	"	1,052
"	24	6 months.	1,025
"	24	"	1,100
"	24	"	1,010
"	24	"	1,120
"	24	"	1,036
"	24	"	1,170
"	24	"	1,165
"	24	"	1,190
"	24	"	1,045
"	24	"	1,120
"	24	"	1,060
"	24	1 year.	1,020
"	24	"	1,080
"	24	"	1,008
"	24	"	1,010
"	24	"	1,040
Alsen.	27	"	990
"	27	"	1,122
"	27	"	1,122
"	27	"	1,248
"	27	"	1,148
"	27	"	1,116

PORTLAND CEMENT.—NEAT CEMENT. (Compression.)

Brand.	Per cent. of Water Used in Mixing.	Time of Set.	Breaking Strength.
Saylor's.	24	24 hours.	8,650
"	24	"	9,200
"	24	"	9,870
"	24	"	9,330
"	24	"	8,910
"	24	"	8,730
"	24	"	10,250
"	24	"	9,540
"	24	2 days.	14,100
"	24	"	13,080
"	24	"	14,220
"	24	"	15,210
"	24	"	13,700
"	24	"	14,860
"	24	"	14,150
"	24	3 days.	15,850
"	24	"	15,200
"	24	"	15,400
"	24	"	16,990
"	24	"	16,000
"	24	"	16,830
"	24	5 days.	20,500
"	24	"	21,680
"	24	"	20,100
"	24	"	21,400
"	24	"	22,000
"	24	"	21,800
"	24	7 days.	20,600
"	24	"	22,370
"	24	"	21,300
"	24	"	20,910
"	24	"	20,750
"	24	"	20,380
"	24	14 days.	23,640
"	24	"	34,820
"	24	"	22,760
"	24	"	25,200
"	24	"	25,180
"	24	"	24,790
"	24	17 days.	31,700
"	24	21 days.	26,000
"	24	"	28,280
"	24	2 months.	37,500
"	24	"	38,500
"	24	"	34,000
"	24	"	42,500
"	24	"	36,000
"	24	"	34,640
"	24	3 months.	35,900
"	24	"	37,000
"	24	"	35,110
"	24	"	36,500
"	24	"	38,570
"	24	"	42,650
"	24	"	39,600
"	24	"	35,370
"	24	6 months.	38,800
"	24	"	38,400
"	24	"	40,400
"	24	1 year.	41,880
"	24	"	47,550
"	24	"	50,000
Alsen.	27	"	38,900
"	27	"	39,500
"	27	"	37,880
"	27	"	36,850
"	27	"	36,150
"	27	"	36,200
"	27	"	42,000
"	27	"	43,000
"	27	"	36,610
"	27	"	39,890
"	27	"	42,300
"	27	"	44,100

PORTLAND CEMENT.—SAND TESTS. (Tension.)

Brand.	Parts Sand to one part Cement.	Per cent. of Water Used in Mixing.	Time of Set.	Breaking Strength.
Saylor's.	3	12	24 hours.	56
"	3	12	"	61
"	3	12	"	72
"	3	12	"	75
"	3	12	2 days.	79
"	3	12	"	80
"	3	12	"	92
"	3	12	"	83
"	3	12	3 days.	126
"	3	12	"	139
"	3	12	"	130
"	3	12	"	129
"	3	12	"	144
"	3	12	5 days.	145
"	3	12	"	165
"	3	12	"	175
"	3	12	"	178
"	3	12	7 days.	180
"	3	12	"	209
"	3	12	"	190
"	3	12	"	177
"	3	12	"	165
"	3	12	"	160
"	3	12	14 days.	186
"	3	12	"	185
"	3	12	"	186
"	3	12	"	190
"	3	12	"	180
"	3	12	"	210
"	3	12	"	211
"	3	12	21 days.	200
"	3	12	30 days.	211
"	3	12	"	230
"	3	12	"	229
"	3	12	"	214
"	3	12	2 months.	217
"	3	12	"	238
"	3	12	"	240
"	3	12	3 months.	271
"	3	12	"	330
"	3	12	"	236
"	3	12	"	284
"	3	12	"	274
"	3	12	6 months.	326
"	3	12	"	382
"	3	12	"	349
"	3	12	"	325
"	3	12	"	330
"	3	12	"	380
"	3	12	"	345
"	3	12	"	345
"	3	12	"	300
"	3	12	"	347
"	3	12	"	333
"	3	12	"	313
"	3	12	1 year.	300
"	3	12	"	322
"	3	12	"	304
"	3	12	"	347
"	3	12	"	302
Alsen.	3	12	"	358
"	3	12	"	308
"	3	12	"	383
"	3	12	"	320
"	3	12	"	304
"	3	12	"	330
"	3	12	"	290
"	3	12	"	292
"	3	12	"	281
"	3	12	"	280
"	3	12	"	283

PORTLAND CEMENT.—SAND TESTS. (Compression.)

Brand.	Parts Sand to one part Cement.	Per cent. of Water Used in Mixing.	Time of Set.	Breaking Strength.
Saylor's.	3	12	24 hours.	1,265
"	3	12	"	1,200
"	3	12	"	1,380
"	3	12	"	1,550
"	3	12	"	1,585
"	3	12	2 days.	1,750
"	3	12	"	1,650
"	3	12	"	1,885
"	3	12	"	1,878
"	3	12	3 days.	2,800
"	3	12	"	3,400
"	3	12	"	3,620
"	3	12	"	3,750
"	3	12	5 days.	3,150
"	3	12	"	3,200
"	3	12	"	3,110
"	3	12	7 days.	3,890
"	3	12	"	4,420
"	3	12	"	4,040
"	3	12	"	3,960
"	3	12	"	3,780
"	3	12	"	3,800
"	3	12	"	3,900
"	3	12	"	3,780
"	3	12	14 days.	5,060
"	3	12	"	5,900
"	3	12	"	5,130
"	3	12	"	4,740
"	3	12	"	4,470
"	3	12	"	4,490
"	3	12	21 days.	5,000
"	3	12	30 days.	4,650
"	3	12	2 months.	7,850
"	3	12	"	8,000
"	3	12	"	8,250
"	3	12	"	8,000
"	3	12	1 year.	8,410
"	3	12	"	8,050
"	3	12	"	8,000
"	3	12	"	8,630
"	3	12	"	9,650
"	3	12	"	9,790
"	3	12	"	9,600
Alsen.	3	12	"	9,980
"	3	12	"	9,980
"	3	12	"	9,650
"	3	12	"	10,000

Steam and Hydraulics.

Boiler Tests.

The two tests following were run as nearly as possible under the same conditions, except for the difference in fuel — New River coal being used in the first test, and New England Gas and Coke Company's coke during the second one.

The tests were made on a battery of four horizontal multitubular boilers 60 inches in diameter, with 84 three-inch tubes 16 feet long. Two of the boilers were supplied with Hawley furnaces, and two with herringbone grates giving air space equal to about 40 per cent. of the grate surface. The four boilers are connected with an unlined steel stack 3 feet in diameter, and 100 feet tall.

The boiler settings were all in good condition. All fires were cleaned three hours before the beginning of the test, three hours before the ending of the test, and as often during the test as was deemed necessary. The thickness and the condition of the fires at the end of the test were made, as near as could be judged, the same as at the beginning.

The greatest chance for error in tests of this sort is in the estimation of the thickness of the fire at the beginning and end of the test. It is assumed that an error of 1 inch may be made in each estimation of the thickness of the fire, and that the errors are cumulative, thus making a total error of 2 inches over the entire grate. Calling the weight of soft coal 48 pounds to the cubic foot, and the weight of coke 25.1 pounds to the cubic foot, the error in weight due to the 2 inches is 739 pounds for coal, 560 pounds for coke. These weights in per cent. of the total weight fired, fix the greatest assumed possible error.

Using soft coal, one day man and one night man took care of the boilers. With coke two men were required on each watch. Firemen familiar with coke fired during the coke trial. The air space of the two herringbone grates was insufficient for the proper burning of the coke, and considerable trouble was found in keeping the grates clear of clinkers which would at times completely shut off the air supply through the grate. The Hawley furnaces worked well with coke. The fused slag ran through the water grates, and gave no trouble on

the lower grates. A thick coke fire was carried on these lower grates, and the area of these grates is included in the total grate area for this test.

As a matter of interest, the pounds of water evaporated from and at 212° F. per dollar of cost has been figured for each case. These figures are based on the prices of New River coal and of New England Coke and Gas Company's coke in lots of 50 tons at the time of the test: *i. e.*, New River coal, $5.00 a ton delivered; coke, $4.50 a ton delivered. The New River coal evaporated 4,124 pounds per dollar. The coke evaporated 3,613 pounds per dollar.

EVAPORATIVE TEST ON BOILER PLANT.

Date, January 2, 1900, 4 P.M., to January 6, 8 A.M.

Duration of test	88 hours.
Barometer	30.42 inches. 14.94 pounds.
Boiler pressure	99.44 pounds.
Temperature of the air	Inside, 97.4° F. Outside, 32.9° F.
Temperature of feed water	13.5° C. = 56.3° F.
Quality of steam, dry steam unity	.992
Kind of coal used	New River.
Moisture in coal, by drying test	2.3 per cent.
Total water fed to boilers	594,943 pounds.

	Boiler No. 4.	Boiler No. 5.	Boiler No. 6.	Boiler No. 7.
Heating surface. Total, 4,558 square feet	1,113	1,113	1,166	1,166
Grate surface. Total, 92.4 square feet	25.9	25.9	20.3	20.3
Ratio of heating surface to grate surface. Total, 49.33 to 1	42.96–1	42.96–1	57.45–1	57.45-1
Coal fired. Total, 70,500 pounds	17,400	16,500	18,600	18,000
Dry coal burned. Total, 68,879 pounds	17,000	16,121	18,172	17,586
Ash and clinker. Total, 6,769 pounds	1,523	1,610	1,798	1,838
Dry combustible burned. Total, 62,110 pounds	15,477	14,511	16,374	15,748
Ash and clinker in per cent. of dry coal, 9.83	8.96	9.99	9.89	10.45

RESULTS.

Chemical analysis of coal:

$H_2O = 1.0$. C = 81.6. H = 4.5. S = 0.2. O = 5.2. N = 1.1. Ash = 6.4.

Heat of combustion of coal	14,380 B. T. U.
Total equivalent evaporation from and at 212° F.	710,362 pounds.
Equivalent evaporation from and at 212° F., per pound of dry coal,	10.31 pounds.
Equivalent evaporation from and at 212° F., per pound of combustible	11.44 pounds.

Equivalent evaporation from and at 212° F., per square foot of heating surface per hour	1.77 pounds.
Coal burned per square foot of grate surface per hour	8.47 pounds.
Boiler, horse-power developed, A. S. M. E. rating	234.
Maximum assumed possible error of test	1.07 per cent.
Thermal efficiency of boiler plant	67.7 per cent.

Gas analysis: Per cent. by volume	CO_2	O	CO
Uptake	7.2	11.8	0.1

DRAUGHT AND TEMPERATURES.

SETTING.	Inches of water.	°F.
Ash pit	.089	...
Above grate	.19	...
At bridge wall	.10	...
Back end	.17	...
Uptake	.26	433

EVAPORATIVE TEST ON BOILER PLANT.

Date, January 9, 1900, 4 P.M., to January 13, 8 A.M.

Duration of test	88 hours.
Barometer	30.50 inches. 14.98 pounds.
Boiler pressure	94.63 pounds.
Temperature of the air	Inside, 97.9° F. Outside, 38.1° F.
Temperature of feed water	12.0° C. = 53.6° F.
Quality of steam, dry steam unity	.990
Kind of coal used	New England Gas and Coke Company's Coke.
Moisture in coke, by drying test	1.65 per cent.
Total water fed to boilers	679,182 pounds.

	Boiler No. 4.	Boiler No. 5.	Boiler No. 6.	Boiler No. 7.
Heating surface. Total, 4,558 square feet	1,113	1,113	1,166	1,166
Grate surface. Total, 133.8 square feet	25.9	25.9	41.0	41.0
Ratio of heating surface to grate surface. Total, 34.07 to 1	42.96–1	42.96–1	28.44–1	28.44–1
Coke fired. Total, 101,490 pounds	21,200	20,090	35,000	25,200
Dry coke burned. Total, 99,815 pounds	20,850	19,759	34,422	24,784
Ash and clinker. Total, 6,875 pounds	1,664	1,457	1,753	2,001
Dry combustible burned. Total, 92,940 pounds	19,186	18,302	32,669	22,783
Ash and clinker in per cent. of dry coke, 6.9	7.9	7 4	5.1	8.1

RESULTS.

Chemical analysis of coke:

$H_2O = 0.1$. $C = 90.0$. $H = 0.5$. $S = 0.2$. $O + N = 1.7$. Ash $= 7.5$.

Heat of combustion of coke	12,820 B. T. U.
Total equivalent evaporation from and at 212° F.	811,460 pounds.
Equivalent evaporation from and at 212° F., per pound of dry coke	8.13 pounds.
Equivalent evaporation from and at 212° F., per pound of combustible	8.73 pounds.
Equivalent evaporation from and at 212° F., per square foot of heating surface per hour	2.02 pounds.
Coke burned per square foot of grate surface per hour	8.48 pounds.
Boiler, horse-power developed, A. S. M. E. rating	267.
Maximum assumed possible error of test	0.56 per cent.
Thermal efficiency of boiler plant	61.26 per cent.

Gas analysis: Per cent. by volume	CO_2	O	CO
Uptake	7.78	12.33	0.0

DRAUGHT AND TEMPERATURES.

SETTING.	Inches of water.	°F.
Ash pit	.007	...
Above grate	.245	...
At bridge wall	.209	...
Back end	.134	...
Uptake	.379	470

HIRN TESTS.

The object of these tests is to show the amount of heat interchanged between the steam and the walls of the cylinder of a steam engine during the different parts of a stroke. The method of carrying out such an analysis was first proposed by Hirn. A complete description of the manner of conducting such tests, together with the thermodynamic equations used in the calculation of the results, will be found in *Technology Quarterly*, Vol. IX, pp. 43 to 50.

The twelve tests given in the tables were all made on the cylinders of a 9″–16″–24″ x 30″ triple expansion engine of the Corliss type made by the E. P. Allis Company. The cylinders are jacketed on both heads and barrels. Between the cylinders there are two reheaters. In tests I to IV (*Technology Quarterly*, Vol. IX) these reheaters were of the double shell type with jacket steam between the two shells. In the tests given below these were replaced by

Wainwright reheaters arranged in such a way that the amount of reheating surface could be varied. The cranks are set 120° apart, the high-pressure crank leading.

Tests I–IV were made using the engine as a compound, the intermediate cylinder being cut out, while the present tests V–XII were run with the low-pressure cylinder cut out. In all tests the entire jacket surface of the cylinders was used. In tests I–IV the jacket was used on the double shell reheater. In tests V–VI one-third of the reheating surface of the Wainwright reheater between the high and intermediate-pressure cylinders was used; this amounted to 26.2 square feet. In tests VII–VIII about two-thirds of the reheating surface was in use: 54.0 square feet. In tests IX–XII the entire surface of the reheater, amounting to 80.2 square feet, was used.

The dimensions of the engine are as follows:

High-Pressure Cylinder.

Dia. of piston = 8.99″. Dia. of piston rod = 2.19″. Stroke = 30″.
Piston displacement: H. E. = 1.102 cu. ft.; C. E. = 1.037 cu. ft.
Clearance in % of P. D.: H. E. = 8.83; C. E = 9.76.
Engine constant: H.E. = .004809; C. E. = .004524.

Intermediate-Pressure Cylinder.

Dia. of piston = 16.01″. Dia. of piston rod = 2.19″. Stroke = 30″.
Piston displacement: H. E. = 3.495 cu. ft.; C. E. = 3.430 cu. ft.
Clearance in % P. D.: H. E. = 10.4; C. E. = 10.9.
Engine constant: H. E. = .01525; C. E. = .01497.

Low-Pressure Cylinder.

Dia. of piston = 24.063″. Dia. of piston rod = 2.16″. Stroke = 30″.
Piston displacement: H. E. = 7.894 cu. ft.; C. E. = 7.831 cu. ft.
Clearance in % P. D.: H. E. = 12.18; C. E. = 12.27.
Engine constant: H. E. = .0345; C. E. = .03417.

Test Number.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Duration of test, minutes	60	60	60	60	60	60	60	60
Total number of revolutions	4,980	4,978	4,929	4,937	4.878	4,923	4,826	4,818
Revolutions per minute	83.00	82.96	82.15	82 28	81.30	81.72	80.43	80.03
Steam consumption during test, pounds:								
Passing through cylinders	1,009	980.5	1,120.0	1,102.0	816 0	725.8	969 5	973.0
Condensation in h. p. jacket	51.1	47.8	50.0	48 3	41 2	43.5	42 4	42 4
in receiver jacket	70.4	63 4	104.0	99 6	82 5	74.0	92 1	94.9
in i. p. jacket	97.2	97.2	82 2	79.4	62 1	58 7	62 1	65.5
Total	1,227.7	1,188 9	1.356.2	1.329.3	1.001.8	902.0	1,166 1	1,175.8
Condensing water for test, pounds	17.924	16,962	19.091	19,106	19.274	19.070	22 755	22 582
Priming, by calorimeter	1.4%	1.4%	1.4%	1.4%	0.9%	0.6%	1.1%	1.2%
Temperature, Fahrenheit:								
Condensed steam	86.4	86.5	88.9	88.5	81.1	78 6	83.1	83.8
Condensing water, cold	48.6	49.1	51.7	52.0	53.4	53.4	53.6	54.0
Condensing water, hot	107.2	112.1	112 8	113.0	98.8	94.3	99.1	99.7
Pressure of the atmosphere, by the barometer, pounds per square inch	14.8	14.8	14.8	14.8	14.7	14.4	14.5	14.6
Boiler pressure, pounds per square inch, absolute	133.5	133.8	133.8	133.8	113.9	113 6	113.8	114.0
Vacuum in condenser, inches of mercury,	25.4	24.8	24.0	23.8	24.1	23.7	25.0	24.3
Events of the stroke, per cent.:								
High-pressure cylinder —								
Cut-off, crank end	20.4	19.7	25.4	24.8	20.4	17.1	25.6	25.4
head end	21.0	20.5	27.7	27.0	15.8	12.1	24.6	25.1
Release, both ends	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Compression, crank end	6 6	6.8	6.1	6.6	6.5	6.5	6.5	6.5
head end	11.3	11.0	10.8	11.0	10.5	10.5	10.5	10.5
Intermediate-pressure cylinder —								
Cut-off, crank end	18.6	18.6	19.3	18.1	26.0	26.0	26.0	26.0
head end	20.0	20.3	17.2	20.1	26.0	26.0	26.0	26.0
Release, both ends	100.0	100.0	100.0	100.0	100.0	100 0	100.0	100.0
Compression, crank end	1.7	1.6	1.3	2.2	1.5	1.5	1.5	1.5
head end	2.5	2.3	2.4	3.3	1.5	1.5	1.5	1.5
Absolute pressures in the cylinder, pounds per square inch:								
High-pressure cylinder —								
Cut-off, crank end	122.3	123.9	123 2	123.0	104.4	101 0	105.5	105.2
head end	123.5	126.0	124 1	123 8	104.0	100.4	105.2	105.1
Release, crank end	35.8	36.0	43 9	44.2	33.3	30 3	38.0	35.7
head end	35.0	34 8	42 4	42 8	26.8	25.2	34 8	34.0
Compression, crank end	37.4	36 6	49 8	49.4	33.6	30.1	39.8	37.7
head end	41.5	41.7	51.7	53.0	33.1	32.4	40.7	41.4
Admission, crank end	83.6	70.5	97.2	87.3	92.8	94.4	74.5	86.7
head end	94.3	92.0	117.6	112.8	95 1	94.8	86 5	86.3

Test Number.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Intermediate-pressure cylinder —								
Cut-off, crank end	32.7	32.2	39.0	41.9	22.8	21.5	27.9	27.5
head end	31.6	31.6	40.5	38.4	24.0	20.1	29.0	29.3
Release, crank end	9.1	8 6	11.0	11.0	8.3	8.0	10 0	10 0
head end	8.6	8.9	10.0	10.3	7.9	7.3	9 4	9.5
Compression, crank end	4 6	5 9	6.0	5.0	3.5	3 5	3 3	3 9
head end	5.4	6.2	7.6	6.5	4.4	4.2	3 8	4 6
Admission, crank end	30.5	33.3	45.4	37.9	23.3	19.4	26 5	28 2
head end	30.8	30.2	44.7	32.2	23.5	20 5	27.9	27 6
Heat equivalents of external work, B. T. U. from areas on indicator diagram to line of absolute vacuum:								
High-pressure cylinder —								
During admission, $A\ W_a$, crank end	2.54	2.43	3.26	3.16	2.20	1.84	2.29	2 80
head end	2 84	2 77	3.76	3.71	1.84	1.39	2 88	2.96
During expansion, $A\ W_b$, crank end	4 68	4.64	4 94	4.92	4 08	3.90	4.15	4.22
head end	4.81	4.84	4.93	4.94	4.00	3.67	4.27	4 36
During exhaust, $A\ W_c$, crank end	3.18	3.05	3.93	3.92	2.47	2.25	2.94	3.04
head end	3.32	3.37	3.99	4.02	2.62	2.37	3 09	2 94
During compres'n, $A\ W_d$, crank end	0.34	0.32	0.43	0.40	0.35	0.33	0.36	0 39
head end	0.71	0.70	0.87	0.88	0 52	0.51	0.62	0 49
Intermediate-pressure cylinder —								
During admission, $A\ W_a$, crank end	2.13	2.20	2.65	2 51	2.14	2.10	2.53	2.60
head end	2.32	2.30	2.31	2.64	2.19	2.08	2.64	2 69
During expansion, $A\ W_b$, crank end	3 95	3.88	4.82	4.89	2 96	2.77	3.78	3.50
head end	3.86	3.89	4.92	4.57	3.08	2.80	3 45	3.59
During exhaust, $A\ W_c$, crank end	1 03	1.13	1.50	1.47	1.12	1.16	1.06	1.09
head end	1.09	1.33	1.30	1.29	0.99	1.02	0.93	1.02
During compres'n, $A\ W_d$, crank end	0.09	0 06	0.10	0.11	0.06	0.04	0.06	0 06
head end	0.13	0.12	0.21	0.17	0.06	0.05	0.09	0.10
Quality of the steam in the cylinder. At admission and at compression the steam was assumed to be dry and saturated:								
High-pressure cylinder —								
At cut-off x_1	73.28	75.04	77.68	76.92	69.4	65.6	73.5	73.7
At release x_2	83.50	85.88	88 50	90.16	86.8	90.6	86.7	94.1
Intermediate-pressure cylinder —								
At cut-off x_1	76.02	77.02	78.98	83.97	77.8	78 2	78 8	77.8
At release x_2	82.96	83.08	86 34	89.48	93.2	98.4	93.1	92.0

Test Number.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
Interchanges of heat between the steam and the walls of the cylinders in B.T.U. Quantities affected by the positive sign are absorbed by the cylinder walls; quantities affected by the negative sign are yielded by the walls:								
High-pressure cylinder —								
Brought in by steam . Q . . .	119.2	115.8	133.7	131.1	98.5	87.4	118.1	118 6
During admission . . Q_a . .	27.3	24.8	25.3	25.6	26.5	27.1	26.9	26.6
During expansion . . Q_b . .	—15.7	—16.1	—18.4	—21.1	—19.1	—23.1	—18.2	—26.0
During exhaust . . . Q_c . .	—14.8	—11.6	—10.4	—8 0	19 9	—15.8	—23.6	—15.4
During compression . Q_d . .	0.8	0 8	1.1	1.0	0.6	0.6	0.8	0.7
Supplied by jacket . . Q_f . .	4.4	4.1	4.3	4.2	3.7	3.9	3.8	3 8
Lost by radiation . . Q_e . .	2.1	2.1	1.8	1.8	1.9	1.9	1.7	1.7
First intermediate receiver —								
Supplied by jacket . . Q_{fR} . .	6.0	5.5	9.0	8.7	7.4	6.6	8 3	8.5
Lost by radiation . . Q_{eR} . .	1.5	1.5	1.3	1.3	1.6	1 6	1.8	1.8
Intermediate-pressure cylinder —								
Brought in by steam . Q' . . .	118.7	114.6	136.2	133.4	99.8	88.9	119.5	119.9
During admission . . Q'_a . .	24 8	24.3	29.5	23.1	22.3	20.0	24.9	25.7
During expansion . . Q'_b . .	—11.7	—10.8	—14.5	—12.4	—16.6	—18.6	—18.6	—18.5
During exhaust . . . Q'_c . .	—20.2	—18.9	—19.4	—14.7	—11.7	—7.6	—12.6	—14.0
During compression . Q'_d . .	0.1	0.1	0.1	0.1	—0.5	0.01	0.07	0.06
Supplied by jacket . . Q'_f . .	8.4	8.4	7.1	6.7	5.5	5.2	5.6	5.9
Lost by radiation . . Q'_e . .	3.3	3.3	2.8	2.8	3.3	3.3	3.4	3.4
Total loss by radiation:								
By preliminary test . ΣQ_e . .	7.0	7.0	5.9	5.9	6.8	6.8	6.8	6.8
By equation	10.0	4.5	7.7	7.3	7.2	7.3	6.2	7.0
Power and economy:								
Heat equivalents of works per stroke:								
High-pressure cylinder AW . .	7.31	7.24	7.67	7.52	6.16	5.34	7.07	7.48
Int.-pressure cylinder AW' . .	9.93	9.44	11.60	11.57	8.07	7.49	10.26	10.11
Totals	17.24	16 68	19.27	19.09	14.23	12 83	17.33	17.59
Total heat furnished by jackets . .	18.8	18.0	20 4	19.6	16.6	15.7	17.7	18.2
Distribution of work:								
High-pressure cylinder	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Intermediate-pressure cylinder . .	1.36	1.32	1.48	1.53	1.28	1.38	1.42	1.47
Total horse-power	66.55	66 28	74 63	74.53	54.12	49.15	64.83	64.92
Steam per horse-power per hour .	18.45	17.95	18.17	17.81	18.49	18.35	17.99	18.12
B.T.U. per horse-power per minute,	318.9	309.5	311.8	306 0	318 3	316.1	312.4	312.6
B.T.U. per horse-power per minute, 2 pounds absolute	316.2	304.8	305.0	299.1	309.4	307.1	310.5	307.5

Explosive Mixtures at Atmospheric Pressure.

The gas apparatus described in Vol. XI of the *Technology Quarterly*, p. 187, having been replaced by one permitting the investigation of explosive mixtures under varying initial pressure, a brief résumé will be given of the results already obtained at atmospheric pressure.

In 1890, Messrs. John W. Glidden and Atherton Loring experimented upon a gas of the following composition by volume:

Illuminants	Marsh gas	Hydrogen	Carbonic oxide
8.03%	33.15%	43.85%	9.47%
Nitrogen	Oxygen	Carbon dioxide	
3.59%	——	1.91%	

They obtained these results:

Proportion of gas in mixture.	Initial temperature.	Time of explosion.	First 0.2 Second.			Maximum pressure.	0.2 Second after Maximum Pressure.				$+\times$ (Maximum pressure − final pressure) $\div$ (2 × proportion of gas).
			Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure $\div$ proportion of gas.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure $\div$ proportion of gas.	Final pressure.	
.0625	20.9	.642	.034	2.3	37	6.4	.09	5.85	94	4.8	90
.067	20.3	.650	.050	3.3	50	9.6	.14	9.11	137	8.0	132
.071	20.1	.772	.10	6.7	94	32.8	.44	28.6	400	28.0	426
.077	21.1	.317	.22	14.7	201	48.8	.62	40.3	524	36.0	551
.083	21.1	.248	.27	18.0	216	55.2	.67	43.6	523	36.8	552
.091	21.1	.176	.42	28.0	308	60.8	.78	50.7	558	40.0	554
.100	20.9	.134	.55	36.7	367	68.0	.81	52.7	527	42.4	552
.111	21.6	.081	.77	51.3	462	76.8	.89	57.9	521	44.0	544
.125	21.1	.061	.88	58.7	470	87.2	1.00	65.0	520	44.8	528

A second series of investigations by Messrs. William A. Johnston and Oscar F. Sager, in 1892, gave the following results:

Illuminating Gas. (Analysis by volume.)

$C_m H_n$	$C H_4$	H_2	$C O$	N_2	O_2	$C O_2$
11.95%	27.56%	38.64%	17.42%	2.18%	0.17%	2.08%

RESULTS OF TESTS.

Proportion of gas in mixture.	Time of explosion.	First 0.2 Second.			Maximum pressure.	0.2 Second after Maximum Pressure.				$+\times$ (Maximum pressure − final pressure) $\div$ (2 proportion of gas).
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure $\div$ proportion of gas.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure $\div$ proportion of gas.	Final pressure.	
.067	.15	0.56	18.7	281	36	1.00	33.3	500	33	518
.071	.13	1.06	35.3	494	55	1.42	47.3	662	38	651
.077	.08	1.31	43.7	568	65	1.58	52.7	685	43	702
.083	.08	1.35	45.0	540	68	1 53	51.0	612	38	636
.091	.07	1.51	50.3	553	73	1.51	50.3	553	38	611
.100	.04	1.52	50.7	507	77	1.52	50.7	507	42	595
.111	.04	1.72	57.3	516	84	1.67	55.7	501	42	567
.125	.03	1.78	59 3	474	88	1.74	58.0	464	42	520
.143	.03	1.66	55.3	387	85	1.66	55.3	387	39	434
.167	.03	1.62	54.0	324	80	1.62	54.0	324	40	360
.200	.10	1.39	46.3	232	72	1.39	46.3	232	43	288

Fuel Water Gas. (Analysis.)

$C_m H_n$, 0.73 %. H_2, 29.02%. CO, 53.95%. N_2, 14.55%. O_2, 1.75%. CO_2, 0.00%.

RESULTS OF TESTS.

Proportion of gas in mixture.	Time of explosion. (Sec.)	First 0.2 Second.				Maximum pressure.	0.2 Second after Maximum Pressure.			
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure $\div$ proportion of gas.	Final pressure.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure $\div$ proportion of gas.	Final pressure.
.083	.50	.03	1.0	12.0	2.5	3.5	.11	3.7	44.4	3.2
.091	.50	.04	1.3	14.3	2.5	7	.22	7.3	80.3	11.0
.100	.45	.06	2.0	20.0	4.5	12	.35	11.7	117	9.0
.111	.40	.11	3.7	33.3	9.0	15	.43	14.3	129	12.0
.125	.25	.51	17.0	136	39.0	40	1.07	35.7	286	29.0
.143	.20	.61	20.3	142	46.0	46	1.11	37.0	259	29.0
.167	.07	1.16	38.7	232	38.0	56	1.25	42.8	257	33.0
.200	.03	1.29	43.0	215	36.0	62	1.34	44.7	224	33 0
.250	.009	1.55	51.7	207	36.0	82	1.56	54.0	216	35.5
.333	.008	1.40	46.7	140	31.0	95	1.47	49.0	147	31.0

HYDROGEN. (Analysis.)

H_2, 99.24%. O_2, .15%. N_2, .60%.

RESULTS OF TESTS.

Proportion of gas in mixture.	Time of explosion. (Sec.)	First 0.2 Second.				Maximum pressure.	0.2 Second after Maximum Pressure.			
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.
.091	.05	.71	23.7	260	21	26	0.67	22.3	245	19
.100	.05	.79	26.3	263	27	28	0.85	28.3	283	23
.111	.03	.85	28.3	255	24	33	0.85	28.3	255	22
.125	.03	1.00	33.3	266	28	37	1.00	33.3	266	26
.143	.008	1.10	36.7	258	29	45	1.10	36.7	258	26
.167	.008	1.11	37.0	222	29	50	1.11	37.0	222	29
.200	.008	1.18	39.3	197	31	65	1.18	39.3	197	31
.250	.008	1.51	50.3	201	31	80	1.51	50.3	202	31
.286	.004	1.40	46.7	163	29	110	1.40	46.7	163	29
.333	.004	1.36	45.3	136	28	105	1.39	46.3	139	28

COMMERCIAL HYDROGEN. (Analysis.)

CH_4, 34.25%. H_2, 23.46%. CO, 3.27%. N_2, 29.53%. O_2, 3.57%. CO_2, 0.00%.

RESULTS OF TESTS.

Proportion of gas in mixture.	Time of explosion. (Sec.)	First 0.2 Second.				Maximum pressure.	0.2 Second after Maximum Pressure.			
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.
.083	.26	0.61	20.3	244	35	37	1.00	33.3	400	31
.091	.15	1.08	36.0	396	50	53	1.38	46.0	506	38
.100	.08	1.36	45.3	453	46	65	1.58	52.7	527	39
.111	.05	1.57	52.3	471	45	76	1.61	53.7	483	39
.125	.03	1.65	55.0	440	44	83	1.66	55.3	442	40
.143	.03	1.73	57.7	404	44	90	1.69	56.3	394	40
.167	.02	1.78	59.3	356	42	95	1.78	59.3	356	39
.200	.01	1.64	54.7	274	41	60	1.66	55.3	277	40
.250	.13	1.24	41.3	165	53	64	1.45	48.3	193	37

It should be stated that the values published in the *Technology Quarterly*, Vol. XI, p. 189, are averages based upon several independent experiments upon mixtures having the same composition. The mixtures were made by students, under the supervision of Mr. Johnston. The composition of the gas was essentially the same as that used during the present year.

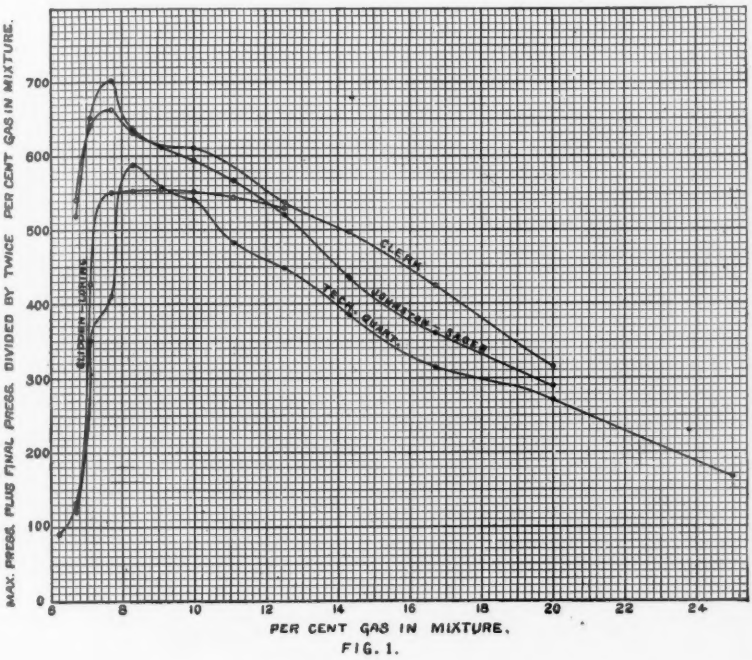


FIG. 1.

The cylinder in which the explosions were made was of cast iron 7 inches in diameter by $8\frac{6}{16}$ inches high. This being nearly identical in size with the one used by Mr. Clark, makes possible an interesting comparison between his results and those given here. Figure 1 shows these results obtained with illuminating gas. The points of each set of observations have been connected by lines to aid the eye. The general character of the results is the same, the specific differences undoubtedly being due to the differences in the composition of the various gases.

Figure 2 shows a group of indicator cards. For the sake of clearness, only those are given which do not intersect in their expansion lines. After the maximum pressure has attained a certain value, any further increase is accompanied by an increase in the rate of cooling, so that although a mixture containing 15.4 per cent. of gas gives the greatest maximum pressure (see results for 1900), a mixture contain-

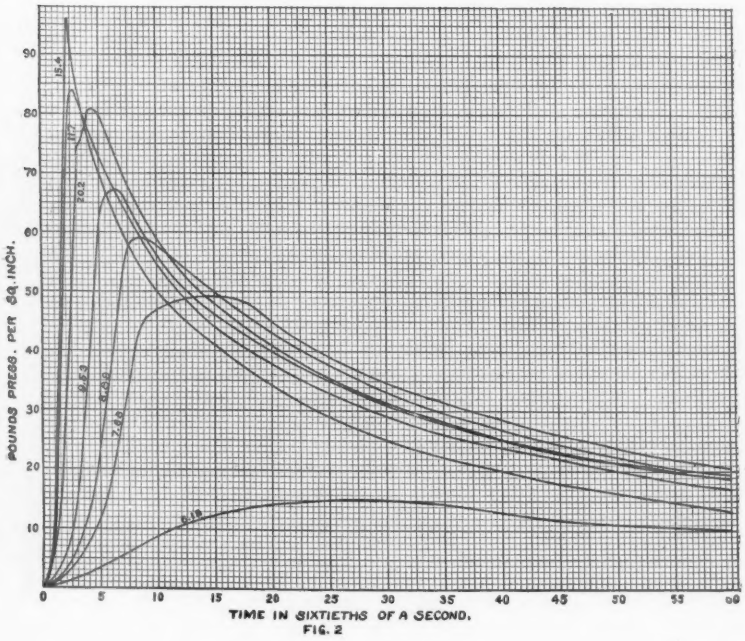


FIG. 2

ing only from 9 per cent. to 10 per cent. gives the greatest average pressure for the first fifth of a second.

Mr. Clark computes the total pressure on the "piston" by taking the average pressure equal to one-half the maximum pressure plus one-half the final pressure. Figure 2 shows that such an assumption on our part would introduce a large and variable error. The following table shows the magnitude and variableness of this error for three different sets of observations :

Glidden and Loring.			Johnston and Sager.			Technology Quarterly.		
Mean pressure ÷ proportion of gas.	Maximum pressure ÷ final pressure ÷ twice proportion of gas.	Error in per cent.	Mean pressure ÷ proportion of gas.	Maximum pressure ÷ final pressure ÷ twice proportion of gas.	Error in per cent.	Mean pressure ÷ proportion of gas.	Maximum pressure ÷ final pressure ÷ twice proportion of gas.	Error in per cent.
94	90	−4.3	500	518	+ 3.6	120	128	+6.7
137	132	−3.6	662	651	− 1.7	364	392	+7.8
400	426	+6.5	685	702	+ 2.5	429	449	+4.7
525	551	+4.9	612	636	+ 3.9	660	666	+0 9
523	552	+5.5	553	611	+10.5	616	638	+3.6
558	554	−0.7	507	595	+17.5	620	615	−0.8
527	552	+4.7	501	567	+13.2	549	599	+9.1
521	544	+4.4	464	520	+12.1	512	536	+4.7
520	528	+1.5	387	434	+12.1	448	469	+4.7
...	...	....	324	360	+11.1	384	420	+9.4
...	...	....	232	288	+24.1	310	330	+6.4
...	...	....	....	....	.....	172	170	−1.2

In the tables above, the mean pressures are based upon the actual areas, as measured with an Amsler planimeter.

This year another series of experiments upon the gas furnished by the city has been made by the fourth-year students, under the supervision of Mr. C. W. Berry. The gas varied considerably from day to day, and this fact undoubtedly accounts for most of the discrepancies which may exist among the results. A good average value for the gas is the following:

Analysis of Boston Gas, 1900.

Illuminants, 12.0%.	Methane (CH_4), 28.9%.	Hydrogen, (H_2) 27.9%.
Carbonic oxide (CO), 25.3%.	Nitrogen (N_2), 3.0%.	Oxygen (O_2), 1.0%.
Carbon dioxide (CO_2), 1.9%.		Total, 100.0%.

EXPLOSIVE MIXTURES OF ILLUMINATING GAS AND AIR. (1900.)

Proportion of gas in mixture.	Time of explosion. (Sec.)	First 0.2 Second.				Maximum pressure.	0.2 Second after Maximum Pressure.				
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.	Final pressure ÷ proportion of gas.
.0618	.417	0.163	5.42	87.7	10.6	15.1	0.44	14.9	241	13.7	222
.0768	.250	0.70	23 3	304	48.9	49.3	1.31	43.7	525	37.5	451
.0829	.192	0.73	24.3	293	57.0	57.0	1.47	49.0	591	41.0	495
.0829	.158	0.88	29.3	354	51.0	51.3	1.45	48.3	583	43.0	519
.0889	.142	1.01	33.7	379	55.0	59.0	1.57	52 3	588	42.0	472
.0945	.120	1.21	40.3	426	54.0	67.0	1.57	52.3	553	42.5	450
.0953	.105	1.27	42.3	444	51.5	67.0	1.55	51.7	543	41.5	435
.0953	.080	1.39	46.3	486	51.5	72.7	1.65	55.0	577	43 0	451
.101	.083	1.51	50.3	498	53 0	72.0	1.69	56.3	557	44.0	436
.105	.087	1.40	46.6	444	51.0	69 5	1.60	53.3	509	42.5	405
.105	.080	1.53	51.0	486	52.0	73.9	1.68	56.0	533	42.9	409
.112	.083	1.46	48.7	435	52.5	71.0	1.72	57.3	512	44.0	393
.114	.060	1.63	54 3	476	50.0	81.1	1.76	58.7	515	43.0	377
.1165	.067	1.58	52.7	452	51.5	77.4	1.78	59.3	509	44.0	378
.117	.046	1 73	57.7	493	49.0	84.0	1.82	60.7	519	44.0	376
.121	.063	1.71	57.0	471	52.0	83.0	1.80	60.0	496	44.0	364
.122	.053	1 70	56 7	465	51.0	85.4	1.82	60.7	498	45.5	373
.125	.043	1.79	59 7	477	48 0	87.0	1.76	58.7	469	43.0	344
.125	.047	1.75	58.3	466	49.0	89.0	1.81	60.3	482	43.0	344
.133	.050	1.76	58.7	441	50.0	86.0	1 80	60.0	451	45.0	338
.133	.043	1.85	61.7	464	49.0	90.5	1.85	61.7	464	43.0	323
.133	.057	1.67	55.7	419	48.0	88.0	1.76	58.7	441	42.0	316
.133	.078	1 54	51.3	386	51.0	66 5	1.65	55.0	414	45.0	338
.1335	.053	1.66	55.3	415	47.5	86.5	1.80	60.0	449	41.6	312
.142	.042	1.85	61.7	435	49.5	90.5	1.84	61.3	432	44.0	310
.143	.062	1.68	56.0	392	55.0	72 0	1.76	58 7	410	46.0	322
.1405	.045	1.83	61.0	416	52.0	92.0	1.86	62.0	423	44.5	304
.154	.038	1.80	60 0	390	46 0	96.0	1.80	60.0	390	42.0	373
.168	.042	1.74	58.0	345	47.0	87.0	1.76	58.7	349	42.0	250
.182	.047	1.70	56.7	322	48.0	87.0	1.82	60.7	334	43.0	236
.202	.072	1.70	56.7	280	54.0	80 8	1.81	60.3	299	45.5	225
.204	.075	1.66	55.3	271	54.0	82.0	1.80	60.0	294	44.5	218
.211	.070	1.62	54.0	256	55.0	78.0	1.87	62.3	295	45.5	216
.222	.080	1.68	56.0	252	55.0	82.0	1.79	59.7	269	45.0	203
.222	.227	.62	20.7	93	58.0	66.5	1.62	54.0	243	44.1	199
.247	No explosion.										

Figure 3 shows the variations in the time of explosion and in the maximum pressure as the percentage of composition varies. It is interesting to note that the quickest explosion gives the maximum pressure.

In 1899 Messrs. Churchill and Clark made an experimental determination of the speed variation of the 36 H. P. Otto gas engine in the laboratory, and found a maximum variation of 4.4 per cent. between the speed of the flywheel at different parts of the stroke.

The variations in the time of explosion of various mixtures, and the fact that the explosion occurs in a gas engine at a definite fraction of a revolution before the beginning of the stroke, make it advisable to find the explosive force for different mixtures for the first fifth of a second as well as for the fifth of a second beginning at the max-

imum pressure, as the stroke of a gas engine is completed within one-fifth of a second. All of the results have been correspondingly computed. Figures 4, 5, and 6 show the changes in the relative values of the different mixtures from these two standpoints.

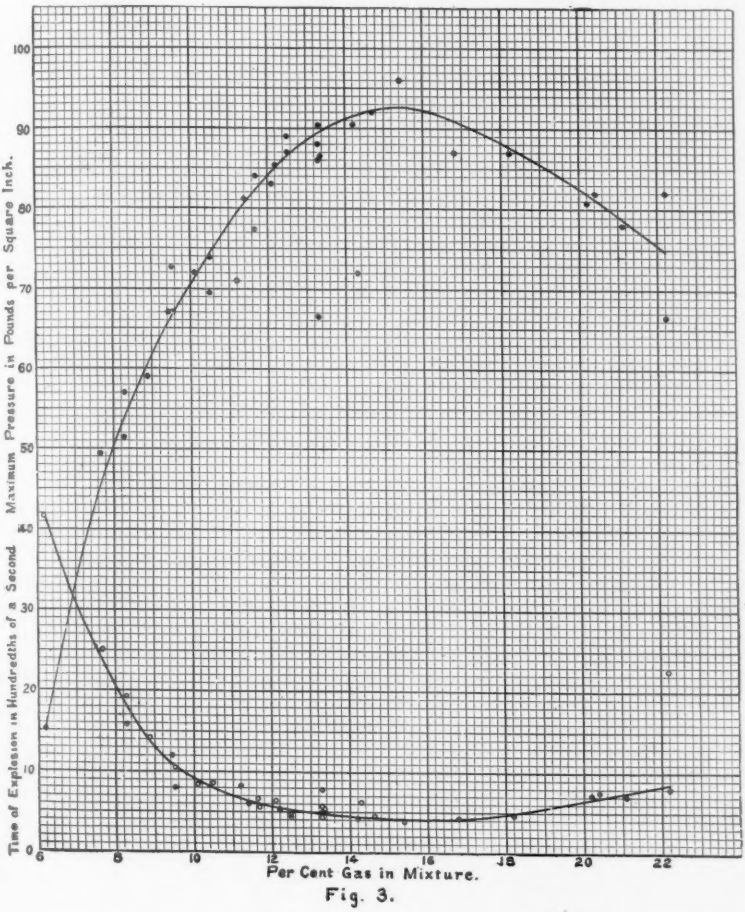


Fig. 3.

What is regarded as the most powerful mixture will depend upon whether we consider the one or the other case. For illuminating gas the maximum value for the first fifth of a second is obtained with about 2 per cent. less of gas in the mixture than for the fifth of a second after maximum pressure. In Figure 6, for example, the most

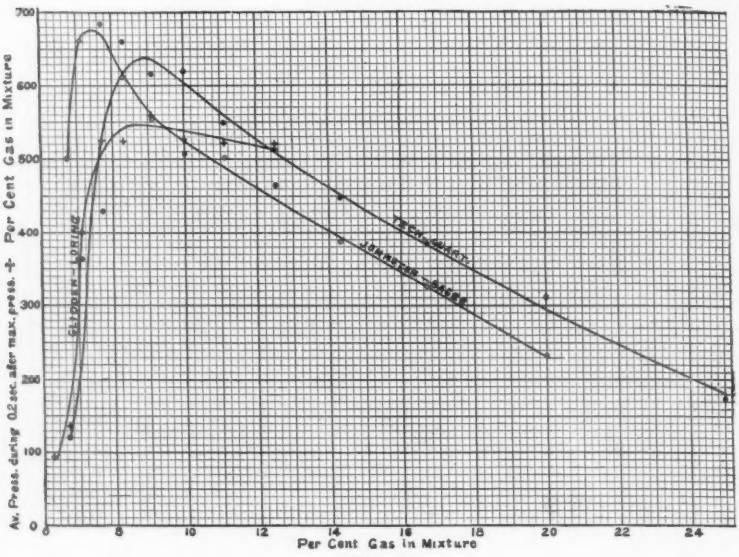

Av. Press. during 0.2 sec. after max. press. ÷ Per Cent Gas in Mixture
Per Cent Gas in Mixture
0
100
200
300
400
500
600
700
6
8
10
12
14
16
18
20
22
24
CLERK - LORING
TECHN. - HEATH
JOHNSON - SATER

Fig. 4.

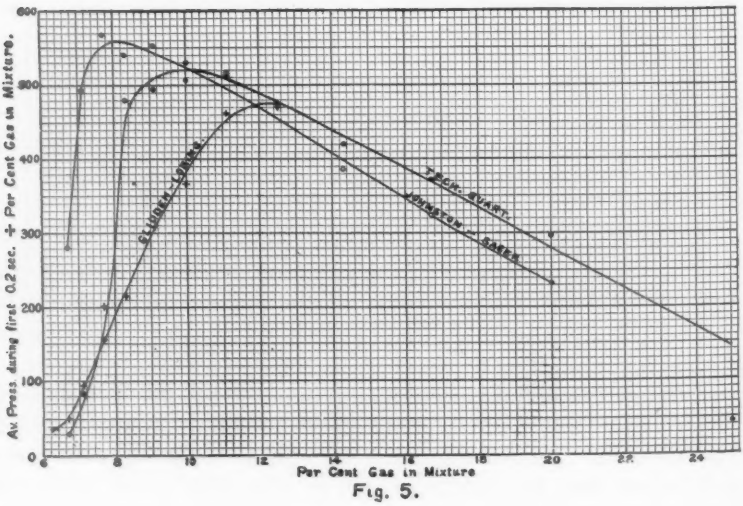

Av. Press. during first 0.2 sec. ÷ Per Cent Gas in Mixture.
Per Cent Gas in Mixture
0
100
200
300
400
500
600
6
8
10
12
14
16
18
20
22
24
CLERK - LORING
TECHN. - HEATH
JOHNSON - SATER

Fig. 5.

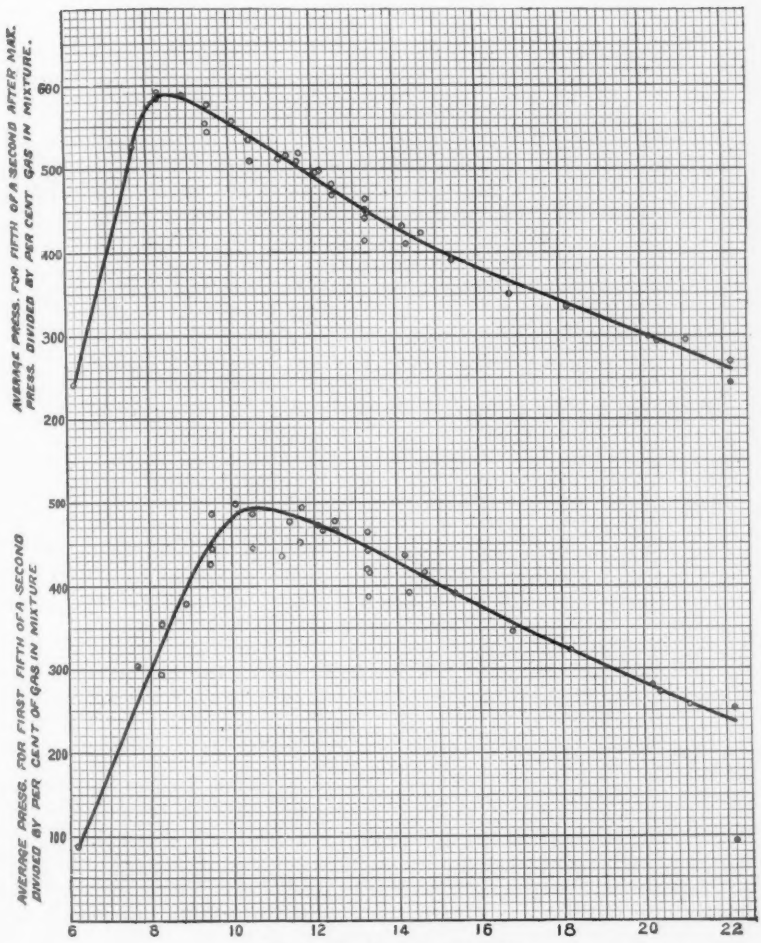


FIG 6.

powerful mixture contains in the one case 8.5 per cent., in the other 10.5 per cent. gas. Since in practice the piston of a gas engine reaches the commencement of its stroke somewhere between the moment of explosion and the attainment of maximum pressure, a mixture containing about 9 per cent. appears the most powerful.

The following series of observations upon mixtures of acetylene and gasolene with air were made by Mr. Arthur H. Brown, in 1899.

ACETYLENE AND AIR.

Proportion of gas in mixture.	Time of explosion. (Sec.)	First 0.2 Second.				Maximum pressure.	0.2 Second after Maximum Pressure.			
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.
.0303	.200	.62	20.6	681	34	35	1.06	35.3	1165	33
.0323	.125	.72	24.0	744	38	38	1.11	37.0	1178	33
.0345	.167	.80	26.6	771	42	42	1.27	42.3	1227	38
.0370	.125	.92	30.6	826	46	47	1.35	45.0	1215	42
.0400	.083	1.21	40.3	1007	51	61	1.60	53.3	1332	43
.0435	.060	1.54	51.3	1180	49	78	1.75	58.3	1340	43
.0470	.050	1.63	54.3	1141	50	82	1.78	59.3	1245	46
.0526	.042	1.65	55.0	1045	49	83	1.82	60.6	1151	45
.0555	.041	1.70	56.6	1019	49	88	1.81	60 3	1085	44
.0588	.042	1.80	60 0	1020	50	96	1.89	62.9	1069	44
.0625	.033	1.87	62.3	997	50	101	1.96	65.3	1045	46
.0667	.028	2.18	72.6	1090	59	113	2.28	75.9	1139	55
.0714	.025	2 28	75.9	1063	60	123	2.32	77.2	1080	58
.0769	.021	2.21	73.6	957	57	130	2.35	78.2	1016	54
.0833	.029	2 33	77.6	932	62	138	2.41	80.2	962	57
.0910	.025	2.30	76 6	843	54	142	2.21	73.6	810	50
.100	.025	2.18	72 6	726	54	150	2.30	76.6	766	51
.111	.025	2.16	71.9	639	55	160	2.27	75.6	680	52
.125	.029	2.20	73.3	587	54	166	2.25	74.9	599	50
.143	.030	2.34	77.9	546	62	172	2.36	78.6	550	58
.167	.033	2.35	78.2	470	66	132	2.46	81.9	492	60
.200	.042	1.56	52.0	260	42	112	1.71	57.0	290	36
.250	.081	1 62	54.0	216	57	95	1.87	62.2	249	46

GASOLENE (86° Sp. gr. 0.648) AND AIR.

Proportion of gas in mixture.	Time of explosion. (Sec.)	First 0.2 Second.				Maximum pressure.	0.2 Second after Maximum Pressure.			
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.
.0151	.083	1.40	46.7	3080	46	70	1.48	49.4	3260	34
.0164	.100	1.41	47.0	2865	49	73	1.53	51.0	3110	36
.0179	.090	1.33	44.3	2480	44	71	1.43	47.7	2670	33
.0196	083	1.36	45.3	2309	46	76	1.55	51.7	2634	35
.0217	.058	1.34	44 7	2055	37	70	1.45	48.4	2225	30
.0244	.067	1.50	50.0	2050	44	80	1.60	53.4	2190	36
.0256	.075	1.60	53.4	2081	50	84	1.69	56.4	2200	40
.0263	.059	1.65	55.0	2089	46	86	1.71	57.0	2164	38
.0273	.083	1.41	47.0	1691	48	78	1.62	54.0	1945	36
.0303	.091	1.40	46.7	1541	52	76	1.60	53.4	1760	38
.0323	.083	1.45	48.4	1500	48	77	1.62	54.0	1675	37
.0345	.083	1.51	50.3	1467	48	77	1.64	54.7	1587	37
.0385	.075	1.37	45.7	1188	47	66	1.50	50.0	1300	38
.0417	.066	1.25	42.7	1025	41	60	1.38	46.0	1104	35
.0476	.066	1.15	38.4	806	39	56	1.32	44.0	925	33

GASOLENE (76° Sp. gr. 0.680) AND AIR.

Proportion of gas in mixture.	Time of explosion. (Sec.)	First 0.2 Second.				Maximum pressure.	0.2 Second after Maximum Pressure.			
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.
.0132	.167	.76	25.3	1925	52	52	1.28	42.7	3240	33
.0141	.117	1.15	38.4	2720	49	62	1.42	47.3	3360	35
.0151	.109	1.26	42.0	2770	48	64	1.45	48.6	2950	35
.0164	.182	.81	27.0	1650	50	51	1.25	41.7	2540	32
.0179	.109	1.27	42.3	2368	50	67	1.53	51.0	2855	36
.0196	.091	1.44	48.0	2441	48	73	1.53	51.0	2600	36
.0217	.082	1.43	47.7	2180	48	76	1.56	52.0	2391	37
.0244	.060	1.62	54.0	2213	45	85	1.63	54.3	2225	36
.0263	.058	1.61	53.7	2040	45	85	1.62	54.0	2052	36
.0278	.058	1.62	54.0	1943	46	84	1.64	54.7	1970	38
.0303	.066	1.49	49.7	1640	45	78	1.60	53.4	1760	37
.0323	.067	1.55	51.7	1602	48	83	1.70	56.7	1760	38
.0345	.100	1.34	44.7	1297	52	75	1.59	53.0	1536	38
.0385	.117	1.10	36.7	955	52	62	1.42	47.3	1230	35
.0417	.133	.98	32.7	761	52	55	1.40	46.7	1121	38
.0476	.210	.39	13.0	273	35	35	1.02	34.0	714	32

STOVE GASOLENE (71° Sp. gr. 0.696) AND AIR.

Proportion of gas in mixture.	Time of explosion. (Sec.)	First 0.2 Second.				Maximum pressure.	0.2 Second after Maximum Pressure.			
		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.		Area. (Sq. in.)	Mean pressure. (Lbs. per sq. in.)	Mean pressure ÷ proportion of gas.	Final pressure.
.0151	.100	1.15	38.4	2543	44	58	1.33	44.3	2925	35
.0164	.106	1.05	35.0	2133	45	55	1.33	44.3	2703	34
.0179	.067	1.47	49.0	2742	44	76	1.58	52.7	2952	35
.0196	.068	1.47	49.0	2497	43	74	1.57	52.4	2672	36
.0217	.066	1.50	50.0	2298	44	76	1.55	51.7	2378	36
.0244	.060	1.36	45.3	2265	36	73	1.32	44.0	1805	29
.0263	.058	1.60	53.4	2027	43	84	1.62	54.0	2052	35
.0278	.058	1.60	53.4	1920	44	85	1.64	54.7	1970	36
.0303	.066	1.53	51.0	1683	46	78	1.62	54.0	1783	37
.0323	.058	1.37	45.7	1416	38	72	1.40	46.7	1450	31
.0345	.050	1.51	50.3	1459	43	78	1.58	52.7	1530	37
.0385	.094	1.34	44.6	1160	49	64	1.50	50.0	1300	36
.0417	.167	.93	31.0	744	60	63	1.46	48.7	1169	35
.0476	.133	.79	26.3	552	42	46	1.18	39.4	827	33

Tests on a 36 H. P. Otto Gas Engine.

Dimensions.

Diameter of cylinder, 11.25″; length of stroke, 18.0″; clearance, 38.74 per cent. of piston displacement.

This engine is about four years old, but has been run altogether only about 2,000 hours. All parts are in excellent condition. The power developed was calculated from indicator cards, taken at intervals of five minutes during a test. The reducing motion used in connection with the indicator was such as to give a correct reproduction of the piston travel, and also to make unnecessary the use of a long cord.

The gas used was the ordinary illuminating gas supplied in Boston, the heat of combustion being about 770 B.T.U. per cubic foot. An analysis of the gas gave the following results:

Carbon dioxide (CO_2), 1.9%.	"Illuminants" (hydrocarbons), 12.0%.	Oxygen (O), 1.0%.
Carbonic Oxide (CO), 25.3%.	Methane (CH_4), 28.9%.	Hydrogen (H), 27.9%.
Nitrogen (N), 3.0%.		Total, 100.0%.

This gas was measured by a 300-light dry meter. Readings of the meter were taken every five minutes during a test, and the rate of consumption was found to be very uniform during any one test.

The power developed was absorbed by an automatic regulating friction brake, located some 50 feet from the engine. This brake was used to absorb power, and no attempt has been made in these tests to find the commercial horse-power, all values given being based on indicated horse-power.

The weight of the cooling water and its rise in temperature were noted for each test. It was found that from 20 to 25 per cent. of the heat of combustion of the gas was carried away by the cooling water.

Revolution counters were attached to the main shaft and to the gas-admitting valve. A 400-pound spring was used in the engine indicator.

The value of n in the exponential equation $P V^n = P_1 V_1^n$ was calculated for the expansion line of each set of indicator diagrams. To do this, the clearance of the engine in per cent. of the piston displacement (which was in every case the volume at the beginning of expansion), the per cent. of the stroke at which the exhaust valve opened, and the absolute pressures at these two points were used.

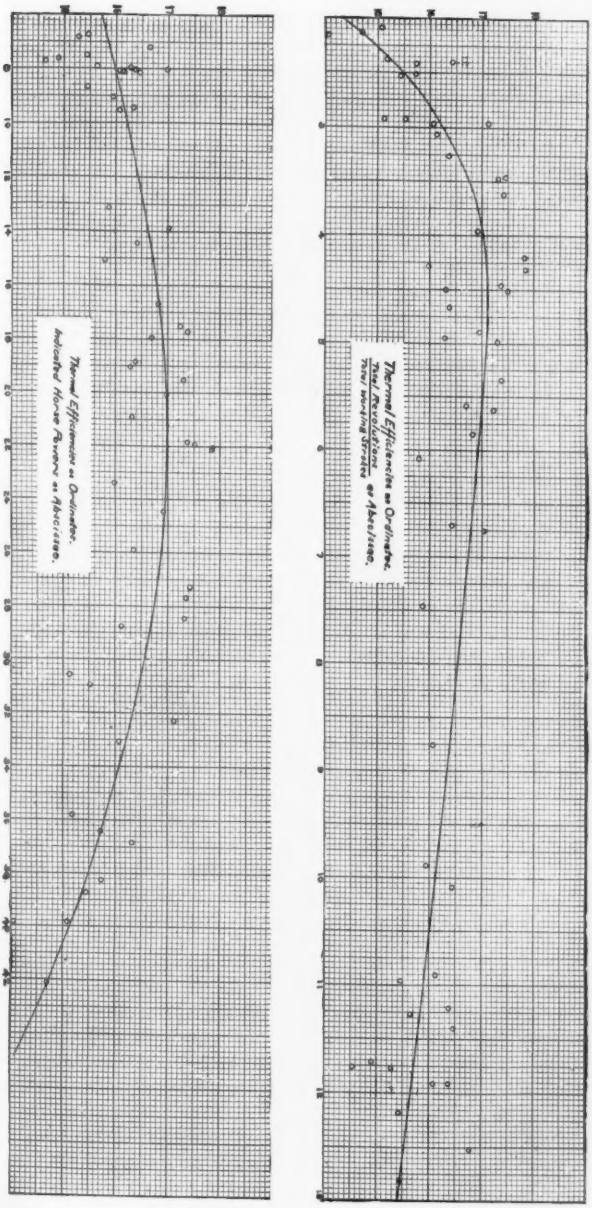

Thermal Efficiencies as Ordinates.
Total Revolutions
Total working Strokes as Abscissæ.
Thermal Efficiencies as Ordinates.
Indicated Horse Powers as Abscissæ.

FIG. 7. — RESULTS OF TESTS UPON THE OTTO GAS ENGINE.

The theoretical efficiency of the engine, as calculated from the formula,

$$\text{Efficiency} = 1 - \left(\frac{\text{volume at end of compression}}{\text{volume at beginning of compression}}\right)^{.405} = .405$$

This is the same for all loads.

The actual thermal efficiencies for this set of tests are shown graphically by the accompanying plots, Figure 7, the ordinates for

TESTS ON OTTO GAS ENGINE, 1900.

Date.	Revolutions per minute.	Working strokes per minute.	Mean effective pressure. (Pounds.)	Gas used in cylinder. (Cubic feet.)	Per cent. of stroke at end of expansion.	Pressure at beginning of expansion. (Lbs. above atmosphere.)	Pressure at end of expansion. (Lbs. above atmosphere.)	Pressure at end of compression. (Lbs. above atmosphere.)	Maximum pressure of explosion. (Lbs. above atmosphere.)
Feb. 8	227.7	19.44	87.25	85.0	96.1	295.0	42.6	60.0	295.0
Feb. 8	229.0	19.20	93 17	83.0	96.6	302 0	45.7	58.6	302.0
Feb. 9	228.6	20.4	87 26	81.0	96.5	291.4	45.0	55.0	291.4
Feb. 12	228 5	19.2	93.61	82.0	96.7	308.6	40.7	55.0	308.6
Feb. 12	228.5	19.4	90.99	81.0	97.0	300 0	40.0	50.0	300.0
Feb. 13	228.2	18.2	97.60	79.0	97 0	298 0	47.9	57.1	298.0
Feb. 13	229 2	18.8	88 40	80.5	95.3	291.4	45.0	55.7	291.4
Feb. 15	230.0	17.5	86.55	74.0	96.1	294.3	45 7	52.9	294.3
Feb. 16	229.5	17.5	91.15	71.5	96 4	284.0	39 4	54.8	284.0
Feb. 16	228 5	17 8	83.76	72.0	96.0	272.0	42.0	52.3	272.0
Feb. 19	228 0	20.0	90 37	82.0	97.5	284.5	41.0	52.5	284.5
Feb. 19	228.6	21.0	85.32	83.0	95 9	264.0	42.9	54.3	264.0
Feb. 20	229.0	20.3	86.70	84.0	94 4	291.0	45.7	60.0	291.0
Feb. 20	227.7	33 7	91.20	134.8	95.3	304.0	45.7	57.1	304.0
Feb. 23	228.1	46.0	91 64	193.5	97.1	318.5	44.0	51.9	318.5
Feb. 23	227.2	48.6	85.77	190.0	97.4	288.0	37.7	52.0	288 0
Feb. 26	226.3	52.4	93.18	204.0	97.1	298.5	43.6	52.1	298.5
Feb. 26	225 6	53 6	91.41	205.0	97.3	312.0	39.0	59.0	312.0
Feb. 27	225.3	56.7	95.50	239.0	97.0	318.9	46 8	54.8	318.9
Feb. 27	224.2	64.7	94.63	262.0	96.7	306 7	48.0	54.7	306.7
Mar. 1	223.5	72.8	87.54	295.0	96 1	294.9	42.3	54.3	294.9
Mar. 1	231.5	93.0	86.51	382.0	95.5	285.0	44.2	50.8	285.0
Mar. 2	228.4	22 6	92.51	95.0	95.9	273.0	44 3	52.1	273.0
Mar. 2	228.3	23.4	90.60	98.5	96.0	272 6	43 8	49.1	272.6
Mar. 5	222.7	93.5	84.81	390.0	96 9	293 5	38 6	54.3	293.5
Mar. 5	228.6	23.1	86.40	93.5	93.4	273.0	45.0	54.7	273.0
Mar. 6	220.0	105.6	83.49	436.5	95.0	298.0	43.0	50.0	298.0
Mar. 8	220.3	101.9	86.60	469.0	98.0	292.8	40.0	54.0	292.8
Mar. 9	222 2	88.4	95.80	402.0	94.6	311.4	47 1	57.9	311.4
Mar. 12	222.3	76.2	89.93	330.0	96 0	311.0	43.1	55.0	311.0
Mar. 13	224.2	61.7	97.94	359.0	96.8	324.0	47.4	56.6	324.0
Mar. 15	225.6	52.6	98 48	242.0	95.7	333 6	48 6	52.1	333.6
Mar. 15	226.9	38 8	95.24	164 0	95.0	346 0	50.0	60.0	346.0
Mar. 16	228 2	30.6	95.35	137.0	96.4	306.4	44.3	55.7	306.4
Mar. 16	228.8	19.5	88.10	88.0	96.9	260.0	42 0	52.1	260.0
Mar. 20	226.7	50.4	92.10	212.5	95 3	302 9	47.6	52.6	302.9
Mar. 20	224.4	63.8	89.90	262.0	98.0	303.0	40 0	53 0	303.0
Mar. 22	222.4	75.0	97.60	340.0	95.7	303.4	45.6	56.4	303.4
Mar. 22	227.0	45.5	95.22	187.0	95.9	324.2	47.0	55 4	324.2
Mar. 23	221 6	103.5	90.21	475.0	95.4	309.0	45.1	51.4	309.0
Mar. 23	226.4	50.8	95.22	208.0	96.3	320 0	48.0	54 9	320.0
Mar. 26	221.6	87.2	98.43	415.0	95.0	331.0	48.0	47.0	331.0
Mar. 26	226.6	50.3	96.44	212.0	96.4	320.1	47.1	56.4	320.1
Mar. 27	223.6	76.1	88.99	334 5	96.1	311.1	46.9	54.1	311.1
Mar. 29	223 9	64.1	98.14	271.5	96 1	331.1	44.3	54.3	331.1
Mar 29	227.0	46.4	95.80	195.5	95.5	320.6	50.0	52.0	320.6
Mar. 30	227.6	33.9	93.05	143.5	95 1	310.7	46 1	53 0	310.7
Mar. 30	226.4	42.3	92 74	168.5	95.6	308.0	43.8	55.3	308.0
Apr. 2	222 6	75.0	95 30	312.0	98 0	312.1	51.0	52.0	312.1
Apr. 3	227.6	40.4	96 20	168 5	97.1	324.6	43.0	56.0	324.6
Apr. 3	227.8	37 5	89 20	158.0	96.0	305.4	43.7	50.9	305.4
Apr. 3	221.5	92.1	88 56	371 0	95 7	295.7	43.7	44.9	295.7
Apr. 5	230.9	41.3	96.06	177 5	97 3	314.9	45 7	56.0	314.9
Apr 9	228 6	20.9	91 96	93.0	94.6	290 6	47.1	54 3	290.6

the lower curve being efficiencies and the abscissæ I.H.P. The upper plot is constructed by using efficiencies as ordinates, and the ratio of total revolutions to working strokes as abscissæ.

By referring to the column in the table giving cost per I.H.P. per hour (based on the price of gas as $1.00 per 1,000 cubic feet), it will be seen that one indicated horse-power costs about $.02 per hour.

TESTS ON OTTO GAS ENGINE, 1900. — *Concluded.*

Date.	Horse-power of engine. (Indicated.)	Gas consumed per I. H. P. per hour. (Cubic feet.)	Heat equivalent of work. (Indicated B. T. U.)	Heat developed by combustion of gas. (B. T. U.)	Thermal efficiency.	Ratio of total revolutions to working stroke.	Cost per I. H. P. per hour. (Gas at $1.00 per 1,000 cu. ft.)	Value of n in $PV^n = P_1V_1^n$ for expansion curve.
Feb. 8	7.66	22.18	19,500	130,900	14.90	11.71	2.22	1.35
Feb. 8	8.09	20.54	20,570	127,800	16.09	11.92	2.05	1.32
Feb. 9	8.05	20.14	20,460	124,800	16.39	11.21	2.01	1.31
Feb. 12	8.12	20.19	20,660	126,300	16.37	11.91	2.02	1.41
Feb. 12	7.98	20.31	20,300	124,700	16.28	11.78	2.03	1.32
Feb. 13	8.03	19.69	20,430	121,700	16.79	12.54	1.97	1.26
Feb. 13	7.52	21.43	19,120	124,000	15.42	12.19	2.14	1.32
Feb. 15	6.84	21.63	17,420	114,000	15.29	13.14	2.16	1.31
Feb. 16	7.20	19.85	18,300	111,100	16.65	13.11	1.99	1.37
Feb. 16	6.74	21.38	17,140	110,900	15.46	12.83	2.14	1.30
Feb. 19	8.17	20.08	20,780	126,300	16.46	11.40	2.01	1.34
Feb. 19	8.09	20.50	20,600	127,800	16.12	10.91	2.05	1.27
Feb. 20	7.95	21.13	20,240	129,300	15.64	11.28	2.11	1.31
Feb. 20	13.89	19.42	35,340	207,600	17.02	6.76	1.94	1.34
Feb. 23	19.06	20.28	48,560	298,000	16.29	4.95	2.03	1.39
Feb. 23	18.84	20.18	47,940	292,600	16.39	4.68	2.02	1.40
Feb. 26	22.05	18.51	56,100	314,200	17.85	4.32	1.85	1.34
Feb. 26	22.14	18.52	56,330	315,700	17.84	4.21	1.85	1.44
Feb. 27	24.46	19.54	62,270	368,100	16.92	3.97	1.95	1.36
Feb. 27	27.68	18.92	70,460	403,400	17.46	3.46	1.89	1.30
Mar. 1	28.79	20.39	73,280	454,300	16.13	3.07	2.05	1.36
Mar. 1	36.41	21.01	92,530	588,300	15 73	2.37	2.10	1.31
Mar. 2	9.44	20.12	24,040	146,300	16.43	10.09	2.01	1.28
Mar. 2	9.58	20.57	24,380	151,700	16.07	8.76	2.06	1.28
Mar 5	35.81	21.77	91,200	600,600	15 18	2.38	2.18	1.40
Mar. 5	9.02	20.73	22,950	144,000	15.94	9.89	2.07	1.28
Mar 6	39.85	21.95	101,400	672,200	15.09	2.08	2.20	1.36
Mar. 8	39.86	23.54	101,400	722,300	14.05	2.16	2.35	1 37
Mar. 9	38.27	21.01	97,400	619,100	15.73	2.51	2.10	1.34
Mar. 12	30.97	21.30	78,830	508,200	15.52	2.93	2.13	1.39
Mar. 13	27.31	18.97	69,500	398,800	17.42	3.63	1.90	1.36
Mar. 15	23.41	20.67	59,580	372,700	15.99	4.29	2.07	1.37
Mar. 15	16.69	19.64	42,490	252,500	16.82	5.85	1.96	1 39
Mar. 16	13.17	20.81	33,520	211,000	15.88	7.47	2.08	1.36
Mar. 16	7.75	22.72	19,720	135,500	14.55	11.76	2.27	1.26
Mar. 20	20.97	20.26	53,380	327,300	16 31	4.50	2.03	1.31
Mar. 20	25.92	20.21	65,970	403,400	16.35	3.52	2.02	1.39
Mar. 22	33 08	20.56	84,220	523,600	16.08	2.97	2.06	1.34
Mar. 22	19.57	19.11	49,820	288,000	17.30	4.99	1.91	1.37
Mar. 23	42.18	22.52	107,400	731,400	14.70	2.14	2.25	1.36
Mar. 23	21.86	19.03	55,630	320.300	17.37	4.46	1.90	1.34
Mar. 26	38.78	21.40	98,700	639,200	15.44	2.54	2.14	1.39
Mar. 26	21.93	18.88	55,800	318,800	17.50	4.51	1.89	1.35
Mar. 27	30.60	21.86	77,870	515,100	15.12	2.93	2.19	1.34
Mar. 29	28.45	19.08	72,410	418,100	17.32	3.49	1.91	1.42
Mar. 29	20.08	19.46	51,120	301,100	16.97	4.89	1.95	1.33
Mar. 30	14.25	20.14	36,270	221,000	16.42	6.71	2.01	1.35
Mar. 30	17.72	19.01	45,110	259,500	17.39	5.35	1.90	1.37
Apr. 2	32.29	19.32	82,210	480,500	17.11	2.97	1.93	1.27
Apr. 3	17.56	19.19	44,700	259,500	17.23	5.63	1.92	1.41
Apr. 3	15.10	20.92	38,430	243,300	15.80	6.08	2.09	1.37
Apr. 3	36.85	20.13	93,800	571,400	16.42	2.40	2.01	1.34
Apr. 5	17.95	19.78	45,660	273,300	16.70	5.59	1.98	1.35
Apr. 9	8.67	21.38	22,140	143,200	15.46	10.91	2.14	1.29

Engine Tests.

The tests made upon the Triple Expansion Engine run as a compound, the low pressure cylinder being cut out, show the economy of this engine when run under the following conditions: (1) no jackets on cylinders, and none of the heating surface of the reheater used; and (2) no jackets on cylinders and the total heating surface of the reheater used. The dimensions of this engine are given in connection with the Hirn tests. A description of the reheater has also been given in the *Technology Quarterly*, Vol. XI, No. 3.

The tests on the Tandem Compound Engine, which has the high pressure cylinder only jacketed, and a coil of pipe in receiver, show the economy of this engine when the jacket on the high pressure cylinder and the reheater are used. The dimensions of this engine are:

	High.	Low.
Diameter of piston, inches	11	19
Diameter of piston rod, inches	1.63	2.13
Stroke, inches		15

The heat consumption per horse-power per minute for the two engines is shown by the plots Figures 8 and 9.

TESTS ON A TRIPLE EXPANSION ENGINE. (Low pressure cylinder cut out.)

Date.	Horse-power.	Steam per H. P. per hour including jacket steam. (Lbs.)	Steam through cylinders per hour. (Lbs.)	Water by Jackets: 1st receiver jacket. (Lbs.)	Revolutions per minute.	Boiler pressure by gauge.	Vacuum in condenser. (Inches of mercury.)	Barometer. (Ins.)
1900.								
Mar. 2	45.9	21 0	966	....	82.2	98.7	24.2	30.0
Mar. 5	47.0	20.9	984	....	82.0	99.4	23.9	30.1
Feb. 23	48.6	20.6	1,003	....	82.2	99.5	23.8	30.0
Mar. 8	52.2	21.0	1,100	....	81.3	99.3	22.7	30.2
Mar. 6	51.3	20.9	1,070	....	81.2	99.4	23.7	30.1
Mar. 1	57.0	19.9	1,138	....	81.4	98.9	24.5	30.1
Mar. 12	60.1	20.2	1,212	....	81.9	99.4	23.9	30.1
Feb. 27	61.0	19.9	1,215	....	81.1	97.8	24.2	30.2
Mar. 19	65 5	19.6	1,286	....	81.7	98 8	23.4	30.1
Mar. 16	53.5	19.9	1,268	....	81.6	99.5	23.7	29.6
Mar. 15	67.0	20.2	1,351	....	80.9	99.6	24.5	30.1
Mar. 20	69.1	20.0	1,381	....	81.1	99.7	23.8	29.6
Mar. 13	71.2	20.4	1,454	....	80.8	99.4	24.3	30.1
Apr. 27	46.2	19.4	792	104	84.7	99.1	24.4	29.7
May 17	47.6	18 8	792	104	85.1	98.9	25.9	30 0
May 3	50.8	19.5	869	118	81.5	96.9	23.8	29.4
Apr. 23	56.5	19.0	970	107	83.4	99.3	25.5	29.8
Apr. 12	55.9	18.8	964	98	83.1	99.2	25.4	30.1
Mar. 29	57.7	18.8	995	97	82.9	98 9	25.2	29.7
Apr. 30	61.8	19.1	1,054	125	82.6	99.2	24.1	29.5
Apr. 3	64.1	18.9	1,097	111	82.7	99.3	24.6	29.9
May 10	72.5	17.5	1,169	97	82.5	98.6	24.6	29.9
Apr. 2	70.3	18.3	1,194	91	81.7	99.5	24.7	29.9
May 8	74.1	17.7	1,208	105	82.0	99.3	24.9	29.8
Apr 17	71.3	17.5	1,186	59	82.1	98.6	25.2	30.1
Mar. 26	75.2	17.7	1,257	73	81.3	99.3	24.1	29.9
Apr. 5	77.2	20.7	1,347	97	81.1	99.4	25.4	29.9

TESTS ON A TRIPLE EXPANSION ENGINE. (Low pressure cylinder cut out.) — *Continued.*

HIGH PRESSURE CYLINDER.

DATE.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off.	Per cent. of steam in cylinder at release.	M. E. P. Crank end.	M. E. P. Head end.	Horse-power.
1900.										
Mar. 2	97.4	16.8	92.5	15.2	7.5	62.1	79.2	42.0	37.1	30.3
Mar. 5	97.9	17.9	88.2	15.2	6.2	62.7	78.3	44.0	38.6	31.5
Feb. 23	96.9	18.8	89.0	12.9	4.9	66.2	71.8	44.2	41.1	32.7
Mar. 8	98.2	21.2	94.3	19.8	8.8	64.7	79.4	46.8	42.6	33.9
Mar. 6	97.3	22.0	87.3	18.3	7.6	64.1	78.3	45.9	42.0	33.3
Mar. 1	97.8	25.4	91.8	23.4	11.6	69.3	82.7	47.9	45.8	35.6
Mar. 12	98.2	26.7	92.0	23.1	8.6	68.8	79.4	53.8	47.5	38.6
Feb. 27	97.6	27.9	88.1	23.2	6.3	68.6	79.5	53.5	52.2	40.0
Mar. 19	97.7	31.4	87.9	27.5	9.0	70.7	83.0	57.7	50.8	41.3
Mar. 16	98.1	31.4	88.8	27.0	14.9	70.9	81.1	52.7	46.4	37.7
Mar. 15	98.7	35.0	89.4	29.5	16.5	72.4	80.3	54.3	48.7	38.8
Mar. 20	97.7	36.5	89.4	30.0	18.7	73.1	78.8	55.4	47.0	38.7
Mar. 13	96.9	40.5	88.0	35.1	19.6	74.7	83.2	55.6	49.8	39.7
Apr. 27	95.8	11.6	87.2	10.4	11.1	56.0	80.1	33.6	20.0	21.0
May 17	97.8	12.3	90.3	11.9	14.3	38.7	54.2	33.0	20.8	21.2
May 3	95.2	17.4	85.7	11.8	14.3	63.1	73.6	34.3	26.8	23.1
Apr. 23	95.6	18.6	86.6	13.5	15.1	61.5	72.8	38.2	26.6	25.1
Apr. 12	96.3	20.7	90.0	17.5	19.6	67.4	81.7	37.4	27.5	25.0
Mar. 29	98.3	22.3	89.0	19.3	21.9	67.6	82.1	36.0	30.6	25.7
Apr. 30	95.7	25.2	85.6	20.3	19.5	68.4	80.6	41.0	32.0	28.0
Apr. 3	96.4	25.9	88.5	22.4	19.5	69.4	82.5	41.5	35.7	29.7
May 10	98.1	29.0	90.4	23.9	22.0	72.0	80.3	44.4	38.5	31.9
Apr. 2	97.9	33.0	91.8	28.7	29.3	76.6	85.3	40.3	36.2	29.1
May 8	98.2	33.0	88.5	28.3	29.6	73.9	83.9	42.9	36.9	30.4
Apr. 17	96.1	34.4	85.6	27.8	26.7	76.5	85.6	43.5	38.7	31.4
Mar. 26	97.9	36.4	95.8	18.1	20.7	64.2	80.3	52.6	47.0	37.7
Apr. 5	97 2	40.1	93.2	36.2	34.8	79.6	87.0	43.4	40.8	31.9

TESTS ON A TRIPLE EXPANSION ENGINE. (Low pressure cylinder cut out.) — *Concluded.*

INTERMEDIATE PRESSURE CYLINDER USED AS LOW PRESSURE CYLINDER.

DATE.	Initial pressure.	Per cent of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off.	Per cent. of steam in cylinder at release.	M. E. P. crank end.	M. E. P. head end.	Horse-power.	B. T. U. per H. P. per minute actual vacuum.	B. T. U. per H. P. per minute reduced to 2 lbs. absolute.
Mar. 2	3.1	18.0	0.6	—7.9	—10 7	35.9	66.1	6.18	6.43	15.7	374.8	363.3
Mar. 5	2.6	22.0	0.4	—8.2	—10.7	41.1	62.0	6.41	6.10	15.5	371.4	357.3
Feb. 23	1.1	27.0	—0.8	—7.8	—10.2	43.0	65.0	6.69	6.14	15.9	358.7	353.1
Mar. 8	5.6	22.2	2.6	—7.1	—10.1	41.4	68.2	7.47	7.49	18.4	371.0	351.7
Mar. 6	4.5	23.0	1.0	—7.5	—10.5	40.4	63.0	7.86	6.83	18.0	369.8	355.8
Mar. 1	7.7	17.6	4.7	—7.1	—11.2	38.9	64.2	9.11	8.33	21.4	345.3	348.4
Mar. 12	5.0	29.0	2.0	—6.1	—10.5	44.9	66.9	8.84	8.57	21.5	358.0	348.7
Feb. 27	2.6	36.5	—0.3	—6.8	—11.1	47.6	61.8	8.96	8.19	21.0	354.4	346.1
Mar. 19	5.6	32.5	2.3	—6.1	—10.7	46.8	63.3	9.94	9.66	24.2	348.0	340.6
Mar. 16	10.7	22.0	6.0	—5.9	—10.5	42.8	62.7	10.64	10.36	25.9	355.1	350.5
Mar. 15	12.1	21.5	8.2	—5 4	—11.1	43.6	63.8	11.44	11.63	28.2	359.7	353.4
Mar. 20	14.1	22.2	8.4	—6.3	—10.9	43.9	64.1	12.31	12.52	30.4	356.2	349.8
Mar. 13	15.7	22.5	8.9	—4.6	—10 6	43.2	64.0	13.15	12.66	31.5	363.7	357.8
Apr. 27	6.7	27.0	3.6	—7.5	—11.4	71.9	86.6	10.02	9.70	25.2	339.0	330.5
May 17	9.1	22.2	4.4	—7.9	—12.2	54.4	73.0	10.24	10.29	26.4	330.5	329.0
May 3	10.0	26.5	6.6	—6.1	—10.9	71.6	87.5	11.10	11.40	27.6	333.0	330.0
Apr. 23	12.7	22.1	8.2	—5.9	—11.4	63.1	85.2	12.58	12.34	31.4	336.8	336.2
Apr. 12	15.6	16.8	11.1	—6.0	—11.6	59.8	85.2	12.65	11.93	30.9	334.2	335.0
Mar. 29	16.9	18.2	11.2	—6.3	—11.6	67.6	82.1	13.25	12.26	31.9	334.8	332.4
Apr. 30	13.4	24.6	9.5	—4.9	—11.4	66.8	85.8	13.80	13.30	33.8	334.0	227.0
Apr. 3	15.5	24.5	10.9	—5.1	—11.5	66.6	82.3	14.12	13.34	34.3	328.7	326.5
May 10	14.3	33.0	10.2	—4.2	—12.0	75.8	84.7	16.13	16.47	40.7	310.9	311.2
Apr. 2	27.0	16.1	18.9	—6.4	—12.0	60.1	65.9	16.90	16.50	41.2	322.5	319.1
May 8	20.3	23.7	15 6	—3.6	—12.0	69.4	86.4	17.46	17.73	43.6	318.4	315.3
Apr. 17	20.2	21.1	14.4	—3.7	—11.4	62.6	86.4	16.10	16.06	39.9	309.9	307.7
Mar. 26	14.7	29.7	9.2	—3.6	—11.2	61.8	81.0	15.60	14.90	37.5	313.1	308.1
Apr. 5	26.7	17.0	22.2	—2.6	—11.2	58.0	81.9	18.94	18.08	45.3	330.8	330.6

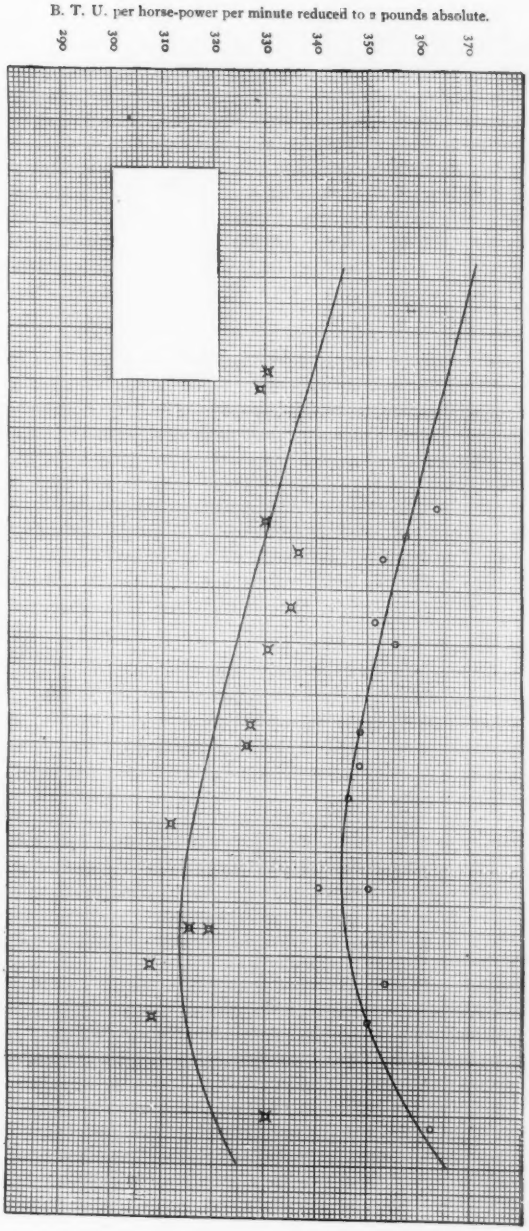


FIG. 8. — RESULTS OF TESTS ON A TRIPLE EXPANSION ENGINE RUN AS A COMPOUND, LOW-PRESSURE CYLINDER CUT OUT.

o No jackets used on cylinders or on reheater. ✕ Total heating surface of reheater used, no jackets on cylinders.

TESTS ON A 11"-19" x 15" TANDEM COMPOUND ENGINE.

Date.	Horse-power.	Steam per H. P. per hour including jacket steam. (Lbs.)	Steam through cylinders per hour. (Lbs.)	Water by Jackets.		Revolutions per minute.	Boiler pressure by gauge.	Vacuum in condenser. (Inches of mercury.)	Barometer. (Inches.)
				High jacket. (Lbs.)	Receiver coil. (Lbs.)				
Mar. 2	28.91	29.40	28.18	22.92	12.29	245.2	102.6	23.35	30.00
Mar. 8	54.51	24.22	23.02	38.01	27.39	244.1	103.0	25.90	30.19
Mar. 9	48.87	24.92	23.72	35.22	24.04	243.6	103.1	25.50	30.14
May 15	49.42	24.48	23.17	38.57	26.83	243.5	103.0	25.00	29.65
Mar. 6	55.30	24.13	23.16	34.10	19.01	243.7	103.2	25.70	30.09
Mar. 13	58.60	23.51	22.28	40.24	31.20	244.1	103.3	26.00	30.10
Mar. 12	52.85	23.58	22.43	36.89	24.60	244.8	103.4	26.40	30.09
Mar. 15	54.03	24.16	23.04	38.01	22.92	244.0	104.0	25.50	30.10
Mar. 19	57.28	23.71	22.47	44.16	26.83	243.5	102.8	26.30	30.08
Mar. 20	56.30	24.17	22.97	41.36	26.83	243.3	103.5	25 00	29.59
Apr. 9	61.37	22.22	21.02	41.93	31.86	244.0	103.0	25.90	29.94
Mar. 16	61.00	23.34	22.21	43.04	25.71	243.7	103.5	24.55	30.08
May 4	76.17	22.46	21.32	50.30	36.34	243.2	126.5	25.00	29.85
May 8	60.23	23.66	22.55	42.22	24.44	243.0	103.2	25.20	29.94
Mar. 22	73.03	22.03	21.02	39 13	34.65	243.0	103.5	25.40	30.13
Mar. 23	67.59	22.63	21.54	43.60	30.75	242.9	103.3	25.30	29.86
Apr. 3	72.10	21.47	20.50	41.36	29.07	243.8	102.8	25.07	29.90
Apr. 12	65.89	23.58	21.70	70.99	52.54	243.0	103.4	25.20	30.11
Mar. 26	73.54	22.07	21.05	41.36	33.55	242.4	103.3	25.50	29.93
Apr. 2	70.36	21.98	20.90	43.04	32.42	242.8	103.3	25.35	29.92
May 14	77.03	21.24	20.30	40.81	32 42	242.6	103.0	25.73	29.98
Mar. 30	70.93	21.80	20.71	46.39	30.75	243.3	103.3	25.30	29.82
Mar. 27	69.94	21.69	20.61	43.60	32.42	243.1	103.1	25.18	29.70
Mar. 29	72.31	22.57	21.59	41.36	33 55	242.7	103.2	25.07	29.95
May 7	81.93	21.98	21.09	41.36	30.75	241.0	102.9	24.70	30.14
May 11	85.71	22.15	21.16	46.39	38.01	241.4	103.0	25.10	29.85
May 17	100.00	21.33	20.54	39.69	39.13	239.0	102.6	25.30	30.04
May 10	101.53	21.31	20.49	44.72	38.57	238.8	102 2	25.90	29.88
May 18	109.34	21.17	20.40	38.01	46.96	236.7	102.6	25.03	29.63

TESTS ON A 11″–19″ x 15″ TANDEM COMPOUND ENGINE. — *Continued.*

HIGH PRESSURE CYLINDER.

DATE.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off.	Per cent. of steam in cylinder at release.	M. E. P. crank end.	M. E. P. head end.	Horse-power.
Mar. 2	91.40	.89	90.90	8.00	9.39	61.69	69.62	8.01	4 38	10.76
Mar. 8	94.45	2.49	92.30	14.25	28.59	51.20	73.39	14.85	13.59	24.70
Mar. 9	95.00	2.60	91.95	13.31	26.25	55.61	75.79	14.00	10.76	21.44
May 15	93.95	2.72	88.45	15 30	32.30	51.38	72.72	13.03	9.38	19.41
Mar. 6	94.00	3.05	90.10	15.10	25.15	50.11	75.46	14.05	12.98	23.44
Mar. 13	94.54	3.74	89.28	15.77	31.14	50.99	74.06	14.71	15.14	25.94
Mar. 12	94.30	3.82	88.95	13.50	16.39	54.89	71.51	13.69	13.02	23.28
Mar. 15	94.70	4.11	92.20	15.10	29.70	52.11	66.07	14.86	12.04	23.34
Mar. 19	94.20	4.80	83.40	16.89	32.72	51.49	74.41	13.88	14.36	24.50
Mar. 20	95.77	4.88	82.68	16.15	34.20	50.71	72.69	13.28	13.46	23.18
Apr. 9	95.40	5.84	84.65	16.25	30.25	54.44	75 48	15.82	14.28	26.13
Mar. 16	95.85	6.33	86.15	18.20	34.85	54.64	75.95	16.14	14.64	26.71
May 4	118.35	7.58	97.00	24.25	44.10	52.07	72.25	18.52	17.10	30.83
May 8	94.85	8.89	75.60	17.70	25.95	55.29	74.72	15.31	14.34	25.65
Mar. 22	95.48	9.52	80.60	20.18	34.24	54.09	75.78	17.56	20.24	32.72
Mar. 23	94.80	9.52	77.60	17.45	34.84	54.17	73.40	16.20	17.35	29.03
Apr. 3	95.35	9.68	80.10	20.65	42.20	54.56	74.47	16.81	17.86	30.11
Apr. 12	97.09	9.77	80.27	20.22	35.55	53.66	71.63	17.25	17.33	29.91
Mar. 26	96.15	9.79	80 77	20.62	37.84	53.91	75.30	18.57	19.48	32.84
Apr. 2	95.23	10.25	77.94	18.51	42.85	54.39	72.67	17.17	17.92	30.34
May 14	95.95	10.80	78.53	21.20	30.80	54.34	78.18	20.51	17.59	32.88
Mar. 30	96.03	10.85	76.75	18.93	37.07	56.07	74.22	17.86	18.23	31.27
Mar. 27	95.65	11.27	74.92	19.24	35.12	58.22	75.60	17.34	19.04	31.50
Mar. 29	95.30	12.35	76.00	21.59	39.68	56.16	75.49	17.75	19.73	32.41
May 7	98.20	14.85	75.90	22.85	31.20	57.39	76.74	20.63	20.44	35.25
May 11	97.35	16.46	71.55	24.70	33.40	54.72	79 30	22.31	21.23	37.40
May 17	97.58	22.18	75.78	28.63	34.03	61 71	80.33	25.92	25.45	43.71
May 10	95.33	23.40	75.78	28.72	35.37	62.36	76.30	25.55	24.88	42.87
May 18	96.28	28.30	75.77	30.00	34.30	66.37	76.92	26.97	28.73	46.96

TESTS ON A 11"-19" x 15" TANDEM COMPOUND ENGINE. — *Concluded.*

LOW PRESSURE CYLINDER.

DATE.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off.	Per cent. of steam in cylinder at release.	M. E. P. crank end.	M. E. P. head end.	Horse-power.	B. T. U. per H. P. per minute actual vacuum.	B. T. U. per H. P. per minute reduced to 2 lbs. absolute.
Mar. 2	2.52	23.0	—3.54	—8.98	—6.98	61.51	87.93	3.53	3.43	18.15	517.1	427.8
Mar. 8	1.19	20.0	—1.69	—8.49	—10.97	46.97	68.77	5.91	5.57	29.81	431.8	428.1
Mar. 9	.30	21.0	—2.55	—8.55	—5.76	48.92	71.16	5.51	5.08	27.43	444.5	433.4
May 15	2.59	20.0	— .62	—7.75	—8.12	53.87	79.31	5.87	5.72	30.01	435.2	424.7
Mar. 6	2.84	19.5	—1.02	—8.09	—10.81	47.03	70.13	5.96	6.33	31.86	430.7	425.4
Mar. 13	2.51	20.5	—1.11	—8.35	—8.58	48.29	66.96	6.29	6.29	32.66	419.7	419.4
Mar. 12	.75	22.0	—2.77	—8.82	—11.47	49.56	67.95	5.78	5.58	29.57	422 2	428.7
Mar. 15	2.25	19.9	— .94	—8.21	—9.14	49.39	68.39	6.12	5.71	30.69	430.5	421.5
Mar. 19	1.82	23.0	—1.71	—8.43	—9.88	51.63	67.78	6.38	6.28	32.78	424.0	427.3
Mar. 20	3.42	21.5	— .45	—7.75	—8 21	51.38	69.10	6.43	6.37	33.12	430.2	421.5
Apr. 9	3.10	20.0	.11	—7.61	—8.41	49.75	70.60	6 99	6.59	35.24	406.2	406.7
Mar. 16	4.09	20.0	— .58	—7.49	—7.69	45.69	71.77	6.90	6.33	34.29	412.9	393.1
May 4	10.08	20.0	4.30	—5.50	—6.13	51.27	72.19	8.68	8.55	45.34	400.1	383.0
May 8	4.75	20.0	.71	—9.00	—7.28	49.69	47.12	6.75	6.63	34.58	420.5	411.0
Mar. 22	5.78	20.7	1.65	—6.97	—7.40	49.85	67.98	8.08	7.52	40.31	392.0	385.7
Mar. 23	5.28	21.5	—1.34	—7.20	—7.89	51.26	67.78	7.63	7.30	38.56	403.2	396.7
Apr. 3	6.55	20.0	2.68	—6.29	—7.79	52.17	73.50	8.18	8 02	41.99	381.9	373.8
Apr. 12	4.70	20.0	1.35	—7.26	—7.31	49.65	67.53	6.98	6.94	35.98	416.2	405.3
Mar. 26	5.61	21.5	1.79	—6.76	—8.05	50.11	67.38	8.14	7.65	40.70	393.6	390.2
Apr. 2	6.06	20.0	2.13	—6.78	—7.40	50.59	69.59	7.95	7.55	40.02	391.3	385.7
May 14	7.12	20.0	2.84	—6.31	—8.29	50.13	72.76	8.69	8.42	44.15	379.3	377.7
Mar. 30	5.43	20.0	1.79	—6.78	—7.94	49.84	69.73	7.79	7.54	39.66	388.2	383.2
Mar. 27	5.68	20.0	2.19	—7.18	—7.91	51.65	66.76	7.63	7.29	38.44	386.4	381.6
Mar. 29	6 07	20.0	2.11	—6.50	—7.60	47.83	68.07	8.00	7.46	39.90	402.3	393.5
May 7	9.80	20.0	5.24	—5.43	—6.31	50.44	68.84	9.12	9.09	46.68	389.2	377.1
May 11	10.65	20.0	5.11	—4.96	—6.97	48.14	68.79	9.67	9.16	48 31	394.0	388.4
May 17	15.45	20.0	9.05	—5.32	—6 83	50.55	61.41	11.45	10.70	56.29	380.1	375.8
May 10	14.35	20.0	8.85	—3.59	—6.94	49.48	68.17	11.71	11.39	58,66	381.8	382 3
May 18	16.69	20.0	10.45	—3.25	—6.04	48.43	66.62	12.67	12.11	62.38	378.0	374.6

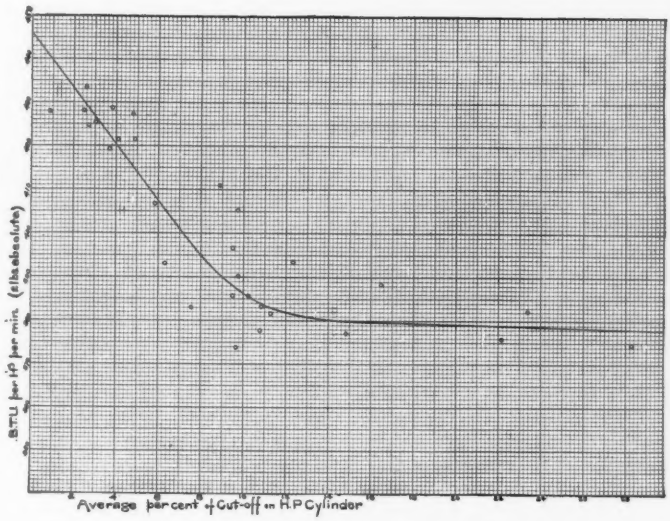


FIG. 9. — RESULTS OF TESTS ON A MCINTOSH AND SEYMOUR TANDEM COMPOUND ENGINE.

Injector Tests.

The following tests were made on a Hancock Locomotive Inspirator, size No. 4 C. The duration of each test was 30 minutes, observations being taken at intervals of 3 minutes, and in each case the inspirator had been in full operation for some time before the start was made. The pressures in the steam pipe and delivery pipe were measured by Bourdon gauges, and the lift was measured directly in feet. The weight of water fed, and the weight discharged were taken, and the amount of steam used was obtained by subtracting the feed from the discharge. It was assumed that the steam contained 1 per cent. of moisture.

HANCOCK LOCOMOTIVE INSPIRATOR, NO. 4 C.

Number of test.	Temperature of suction. (Fahrenheit.)	Temperature of discharge. (Fahrenheit.)	Pressure of steam. (Lbs. per inch.)	Lift in feet.	Discharge pressure. (Lbs. per inch.)	Water delivered per minute. (Lbs.)	Water delivered per pound of steam used.	Mechanical work as a pump, in foot-pounds per minute.	Work as a pump and heater. (B. T. U. per minute.)	Percentage efficiency as a pump.	Duty as a pump.	Percentage efficiency as pump and heater.
1	47.1	138.9	83.7	5.0	89.9	102.9	11.8	22,270	8,680	.309	2,410,000	93.8
2	49.6	138.0	78.1	4.8	84.0	100.1	12.8	20,270	8,190	.313	2,435,000	98.4
3	45.7	133.9	78.7	5.6	85.7	100.7	12.8	20,830	8,210	.313	2,438,000	96.0
4	42.2	120.0	57.7	9.2	63.4	89.9	14.4	14,170	6,520	.270	2,098,000	96.7
5	50.4	146.7	83.7	14.5	88.5	95.4	11.6	21,210	8,430	.313	2,436,000	96.6
6	41.9	139.0	82.9	14.7	88.6	95.8	11.8	21,310	8,550	.318	2,474,000	99.3
7	43.9	139.0	80.8	14.8	85.8	95.0	12.1	20,510	8,350	.316	2,455,000	99.7
8	36.7	125.0	82 3	11.7	86.9	110.0	12.7	23,670	9,010	.325	2,533,000	96.3
9	41.0	130.8	83.3	15.6	88.2	107.0	12.7	23,740	8,880	.338	2,630,000	98.6
10	40.5	130.8	85.2	15.9	88.2	108.3	12.7	24,060	9,040	.293	2,280,000	99.0
11	44.9	135.5	84.2	16.0	88.9	106.2	12.0	23,800	8,900	.323	2,516,000	94.1
12	41.5	140 9	85.2	17.9	88.7	98.2	11.1	22,130	8,880	.302	2,350,000	94.5
13	41.0	131.7	84 1	16.2	87.3	108.0	12.1	23,800	9,020	.320	2,492,000	94.5
14	63.3	155 0	82.5	17.1	85.8	102.0	11.6	22,340	8,590	.310	2,412,000	92.7
15	50.5	140.9	83.6	16.4	88.2	107.5	11.9	23,980	8,920	.320	2,490,000	92.6
16	40.3	141.1	85.5	18.8	88.1	98.0	10.8	22,030	9,000	.292	2,275,000	93.0
17	43.5	134.7	85.3	17.1	90.4	107.0	12.3	24,550	9,040	.338	2,628,000	96.8
18	42.6	145.4	84.2	19.5	92.2	93.7	11.2	22,080	8,820	.319	2,485,000	99.2
19	55.9	145.1	84.4	15.1	85.6	106.4	12.0	22,980	8,750	.314	2,443,000	93.0
20	55.6	144.0	86.6	15.1	88.5	105.9	12.2	23,590	8,630	.329	2,564,000	93.8
21	41.8	137.2	79.3	19.4	87.7	96.2	11.8	21,570	8,432	.319	2,481,000	97.0
22	53.9	147.0	81.4	17.1	85.7	101.3	12.1	22,120	8,690	.321	2,501,000	98.3
23	53.1	150.8	85.5	17.1	96.6	97.3	11.2	23,730	8,700	.334	2,596,000	95.2
24	57.9	145.9	84.3	12.0	92.5	107.3	12.4	24,900	8,730	.344	2,680,000	95.1
25	45.5	135.3	89.6	14.9	91.6	107.7	12.7	24,990	8,950	.349	2,720,000	98.6
26	46 6	178.5	85.1	22.0	90.2	72.1	8.56	16,950	8,440	252	1,962,000	97.7
27	48.2	133.4	84.8	5.6	96.5	112.8	12.9	26,220	8,900	.361	2,810,000	95.4
28	52.2	135.9	82.7	5.1	96.5	111.5	13.4	25,880	8,680	.374	2,909,000	97.6
29	45.0	131.5	85.3	6.0	98.7	112.9	12.8	26,830	9,030	.363	2,827,000	95.2
30	46.2	132.4	85.2	6.7	97.7	112.1	13.4	26,450	8,900	.380	2,957,000	99.5
31	48.2	132.4	84.0	3.4	95.8	113.4	13.6	25,900	8,890	.373	2,897,000	99.4

Ejector Tests.

The following tests were made on a Hancock Ejector, size No. 6. This ejector has an iron body, and is fitted with a 1″ steam supply pipe and 2″ suction and discharge pipes. The steam nozzle is $\frac{3}{8}$″ in diameter. The tests were made to determine the capacity and efficiency of the ejector for pumping water out of a cistern. The duration of each test was thirty minutes, observations being taken at intervals of three minutes, and in each case the ejector had been in full operation for some time before the start was made. The amount of steam used was determined by placing an orifice 0.3516″ in diameter between the ejector and the boiler, and calculating the flow through it by Napier's formula. The two steam pressures were measured by Bourdon gauges; the lift and the discharge head, by mercury columns connected to the suction and discharge pipes. The water discharged was weighed in tanks. It was assumed that the steam on the boiler side of the orifice contained 1 per cent. of moisture.

HANCOCK EJECTOR, NO. 6.

Number of test.	Temperature of suction. (Fahrenheit.)	Temperature of discharge (Fahrenheit.)	Boiler pressure in pounds per sq. in.	Pressure of steam at ejector in pounds per sq. in.	Lift in feet.	Discharge head in feet.	Pounds of water pumped per minute.	Pounds of water pumped per pound of steam.	Work as a pump. (Foot-pounds per minute.)	Work as pump and heater. (B.T.U. per minute.)	Percentage efficiency as a pump.	Duty as a pump.
1	82.6	101.0	52.4	35.5	15.1	2.8	308	56.6	5,540	5,650	.120	930,000
2	78.1	99 3	75.9	53.3	17.2	2.8	313	42.6	6,280	6,610	.100	776,000
3	85.8	101.8	67.1	46.7	14.8	3.2	409	61.9	7,580	6,520	.134	1,043,000
4	81.7	96.8	67.2	46.4	18.3	0.0	367	55.1	6,520	5,520	.114	886,000
5	87.8	101.6	51.5	34.4	16.5	2.4	312	57.6	5,920	4,280	.121	939,000
6	81.1	98.6	66.7	46.2	16.0	2.9	378	57.3	7,170	6,590	.127	985,000
7	81.1	93 4	65.9	45.2	16.0	3.2	416	63.3	8,060	5,090	.158	1,230,000
8	78.3	97.7	58.7	40.5	12.7	6.9	302	50.6	5,960	5,830	.116	903,000
9	79.9	95 5	69.0	48.1	18.4	1 4	386	57.1	7,710	6,010	.132	1,031,000
10	88.3	104.0	56.0	38.5	16.2	3.7	309	54.5	6,170	4,860	.127	989,000
11	80.2	102.0	73.4	51.6	18.0	3.9	348	48.9	7,650	7,550	.126	979,000
12	80.8	95.0	67.8	47.3	17.7	2.5	381	57.2	7,700	5,390	.134	1,044,000
13	70.9	86.9	68.7	47.9	17.1	3.2	327	48.5	6,670	5,230	.114	888,000
14	79.3	95.4	62.8	41.2	20.1	0.6	334	51.9	8,940	5,360	.160	1,258,000
15	90.0	108 5	66.9	41.2	17.7	3.0	370	64.6	7,520	6,850	.128	999,000
16	80.0	92.9	59.4	41 0	18.4	2.6	357	59.8	7,550	4,580	.139	1,082,000
17	76.3	92.3	66.5	46.1	17.2	3.9	393	59.7	8,300	6,260	.146	1,137,000
18	86.7	101.7	67.0	46.2	18.4	2.7	359	59.1	7,240	5,370	.127	989,000
19	78.1	96.6	68.1	47.8	18.4	2.9	352	52.9	7,510	6,490	.131	1,022,000
20	82.2	98.2	68.9	47.3	19.1	2.5	353	51.6	7,650	5,630	.130	1,014,000
21	71.5	88.5	67.9	47.1	15.1	6.7	389	57.9	8,510	6,620	.146	1,139,000
22	81.5	100.4	69 3	48 7	20.6	1.2	311	45.9	6,790	6,000	.117	913,000
23	87.6	104.4	69.3	48.4	17.8	4.2	357	52.6	7.870	5,970	.136	1,056,000
24	93.0	108.9	64.9	45.2	19.4	2.8	337	52.5	7,510	5,360	.138	1,070,000
25	90.2	107.7	68.2	47 5	19.4	3.2	323	48.1	7,340	5,640	.129	1,007,000
26	86.5	104.2	84.5	63.5	12.7	5.5	411	60.4	7,250	7,250	.130	1,009,000
27	82.0	102.9	66.2	45.5	18.8	7.4	341	51.6	9,000	7,110	.160	1,245,000

A COMPARATIVE STUDY OF THE METHODS USED FOR THE MEASUREMENT OF THE TURBIDITY OF WATER.

By GEORGE C. WHIPPLE and DANIEL D. JACKSON.

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At the present time, several different methods for the measurement of the amount of suspended matter in water are in common use. The most important of these are: 1. The Gravimetric Method. 2. The Wire Method. 3. The Diaphanometer Method. 4. The use of Standards of Comparison. In addition to these are the Disc Method and the Photometer Method, the former applicable only to the comparatively clear water of lakes and reservoirs, and the latter too complicated for ordinary use.

The weight of the suspended matter present in water is found by taking the difference between the total solids before and after filtration through filter paper or through a Pasteur filter.

The wire method, brought into use by Hazen,[1] consists in the observation of the visibility of a platinum wire lowered horizontally into the water. The turbidity scale is furnished by the reciprocal of the depth in inches at which the wire becomes invisible.

The diaphanometer is an instrument devised by Hornung and improved by Parmelee and Ellms,[2] according to which the turbidity is measured by noting the limiting depth of liquid in a tube through which an image at the bottom can be discerned under standard conditions of illumination. The reciprocal scale is used as in the case of the wire method.

The use of kaolin standards of comparison was suggested by Mason,[3] but the authors have found that finely divided silica, obtained from diatomaceous earth, is more satisfactory. According to these

[1] Hazen, Allen. The Filtration of Public Water Supplies. 3d edition. New York: Wiley.

[2] Parmelee and Ellms. On Rapid Methods for the Estimation of the Weight of Suspended Matter in Turbid Waters. *Technology Quarterly*, Vol. xii, No. 2, June, 1899.

[3] Mason, Wm. P. Examination of Water. New York: Wiley.

methods the turbidity of the water is estimated by comparing it with a series of standards of varying turbidity in glass tubes, the standards being prepared by adding definite amounts of silica to distilled water, and the results expressed in parts per million of silica.[1]

These four methods are all fairly satisfactory, but each one has its objections and its limitations. The wire method is the simplest and in many cases the most practical, but its results are only approximately correct, and its use is limited to the hours of bright daylight. The gravimetric method is a long process, and requires careful manipulation and accurate weighing. It takes no account of the state of division of the suspended matter. The diaphanometer method is of more general applicability, but it demands a somewhat elaborate apparatus and a uniform source of light. The use of silica standards of comparison is satisfactory for waters of low turbidity, but less so when the turbidity is very high. The comparisons cannot be well made with artificial light.

Each of these methods, therefore, has its especial field of applicability. The wire method is best adapted to field work and to the study of the turbidity of streams where a single daily observation is sufficient; the diaphanometer is of use in connection with the operation of filters, where it is necessary to continue the observations through the night; and the method of comparison with standards is suitable for general laboratory use. It is neither practical nor desirable, therefore, to limit in any way the use of these various methods, but it is desirable that the relations that exist between the different methods be definitely known. The great importance of the knowledge of the turbidity of our American streams and the magnitude of the field of observation render it imperative that some standard of turbidity shall be universally recognized. Only thus can the results obtained by the different methods be made comparable.

Such a standard must be one that is permanent and capable of exact duplication by different persons, and it must be of such a nature that comparisons may be readily made with any of the methods now in use. The scale of turbidity must be a uniform one, that is, the figures that express the turbidity must be directly proportional to the amount of suspended matter present in any given state of subdivision.

[1] Whipple, G. C., and Jackson, D. D. Silica Standards for the Determination of the Turbidity of Water. *Technology Quarterly*, Vol. xii, No. 4, December, 1899.

With this object in view, the authors have carefully studied the methods now in use and the relations that exist between them, and have reached the following conclusions:

1. No optical method based upon the reciprocal scale can serve as a standard, for such a scale is not a uniform one.

2. In order to obtain a uniform scale with an optical method, it is necessary to calibrate the apparatus used, to correspond with fractional dilutions of a water of definite turbidity.

3. The water of definite turbidity thus used should be considered as the standard of turbidity, and turbidity readings by all methods should be expressed in terms of this standard.

4. Such a definite standard of turbidity is found in the use of finely ground diatomaceous earth, as described by the authors.[1]

The Gravimetric Method.

The determination of the weight of suspended matter in water is not an exact process. For various reasons the results are liable to be in error by 5 parts per million, and at times by more than this amount. With very turbid waters the percentage of error, however, is small, but when the water contains less than 25 parts per million of suspended matter the error is considerable, and when below 5 parts per million the results are practically worthless. If the particles of suspended matter are large, they can be separated from the water by using a close filter-paper; but when the water contains fine silt, clay, etc., it is necessary to use a Pasteur tube.

The Wire Method.

The accurate observation of turbidity by the wire method demands constant conditions of light and a wire of uniform size and brightness. Hazen has stated that the observation should be made in the open air during the middle part of the day, and with the wire shaded from direct sunlight. When the turbidity of the water is such that the wire can be seen at depths greater than about one foot, these conditions are necessary, but when the turbidity is greater than that mentioned, the error from variations in light appears to be less. Thus the authors have found that when the turbidities were greater than .20 on the reciprocal scale, the same readings were obtained at all

[1] Loc. cit.

times during the day when the sun was more than about 10° above the horizon; that readings made under a porch agreed with those in the open air, and differed but little from those made indoors near a large window. Direct sunlight introduces an uncertainty in the readings, and is to be avoided. The nature of the receptacle containing the turbid water has practically no influence on the reading, provided that the diameter is at least twice the depth at which the wire becomes invisible. With receptacles of smaller diameter than this the opacity of the sides has a slight effect on the reading. Accordingly, a water pail 12 inches in diameter should not be used for reading turbidities below .17 on the reciprocal scale. It is preferable to have all the illumination from the top and not to use a glass jar so supported that light may enter from beneath. Differences in reading may be obtained by changing the distance of the eye from the water, as will be seen from the following table:

Distance of eye above surface of water.	Turbidity Readings.			
	No. 1.	No. 2.	No. 3.	No. 4.
4 inches.	.78	.50	.26	.145
8 inches.	.71	.45	.25	.140
12 inches.	.73	.47	.26	.140
20 inches.	.78	.48	.28	.145
50 inches.	.82	.49	.29	.150

As might be expected, these differences are greatest in the case of very turbid waters. The readings are most accurate when the distance of the wire from the eye is about equal to that of normal vision. Throughout the present investigations this distance has been preserved as nearly as possible. In field work, however, it is a common practice to read the rod in a standing position, the wire thus being from four to six feet from the eye.

The size of the platinum wire used has a slight effect on the results. At Pittsburg it was found that a wire 0.4 mm. in diameter gave readings 25 per cent. higher than those obtained with the standard wire, 1 mm. in diameter, and that a wire larger than the standard gave somewhat lower results. The authors have compared turbidities

with wires 1 mm. and 1.5 mm. in diameters, and have obtained results that were in substantial agreement with each other.

Comparisons between the wire method and the disc method[1] have shown that the latter gives somewhat lower results, — that is, the disc can be seen at greater depths than the wire. This is shown by the following table:

Turbidity by wire method.	Turbidity by disc method.	Per cent. which the turbidity by disc method was of the turbidity by wire method.
.098	.087	90
.120	.105	87
.135	.125	91
.183	.165	92
.450	.363	80
.609	.444	73
.917	.625	68

With high turbidities the differences are considerable, but with comparatively clear water the results of the two methods approach each other. Turbidity reading by the wire method may be therefore extended into the clear water of lakes by the substitution of the disc, without the introduction of serious error.

It has been generally assumed that the turbidity of water is inversely proportional to the depth at which the wire becomes invisible, and the reciprocal scale is based upon this assumption. Hazen states "that if a water having a turbidity of 1.00 is mixed with an equal volume of clear water, the mixture will have a turbidity of 0.50, and advantage is taken of this fact for the measurement of high turbidities by dilution." Upon this assumption also depends the accuracy of the elaborate apparatus for turbidity measurement used in the filtration experiments at Washington,[2] D. C., where high turbidities were read by dilution with clear water and where low turbidities were read by admixture with a water of known turbidity.

[1] Whipple, G. C. The Microscopy of Drinking Water, p. 73. New York: Wiley.

[2] Report of Colonel A. M. Miller, on the Feasibility and Propriety of Filtering the Water Supply of Washington, D. C. *Senate Document*, No. 259, 56th Congress, 1st session.

According to the experience of the authors, the assumption that the turbidity is inversely proportional to the depth of the disappearing wire, is only approximately correct when the distance of the wire from the eye is substantially that of normal vision.[1] If a water in which the disappearing wire has a depth of one inch is diluted with an equal volume of clear water, the wire will not disappear at a depth of exactly two inches, but at a depth somewhat less than two inches; or, in other words, a turbid water, when diluted with an equal volume of clear water, will have a turbidity, according to the reciprocal scale, of somewhat more than one-half the original turbidity. This has been shown by scores of observations, but a single example will serve as an illustration.

	Turbidity calculated according to the reciprocal scale.	Observed turbidity.
Original water	1.60	1.60
Diluted $\frac{1}{2}$ with clear water . . .	.80	.83
Diluted $\frac{1}{4}$ with clear water . . .	.40	.47
Diluted $\frac{1}{8}$ with clear water . . .	.20	.26
Diluted $\frac{1}{16}$ with clear water . . .	.10	.145

This fact has been noticed by other observers, but its important bearing upon the value of turbidity readings, expressed in terms of the reciprocal scale, has not been appreciated. Parmelee and Ellms, as well as Hazen, found that the ratio between the weight of suspended matter and turbidity increased with the turbidity, but the reason for this was attributed to the differences in the size of the suspended particles, — larger particles as a rule being present in greater amounts in the water of any stream during periods when the turbidities are high. If, however, it is true that turbid waters diluted one-half do not have half the turbidity according to the reciprocal scale, it follows that the present method of stating results is not the best one, as the figures that express turbidity do not give true comparisons of the amount of suspended matter present. The size of the particles does have, indeed, an important effect upon the turbidity, and a given weight of fine clay particles does produce a greater opacity in the

[1] The assumption is more nearly correct, however, for observations made with the eye at a distance of five or six feet from the wire, as in Hazen's practice, and this fact should be remembered in the present discussion.

water than the same weight of coarse silt particles; but the effect of the water itself also has an important influence. The amount of absorption of light by water is greater than is sometimes supposed. Wild has given the following coefficients of absorption for distilled water:

Temperature.	Intensity of light after passing through 10 cm. of distilled water.
24.4° C	0.9179
17.0	0.9397
6.2	0.9477

Not only does the absorption vary with the temperature, it varies greatly with the character of the dissolved substances. In colored waters the absorption is much greater than in clear waters, but the coefficient is at present unknown. In clear waters the intensity of the light at various depths may be stated approximately as follows:

Depth in inches.	Intensity of light.
0	1.00
1	.98
5	.92
10	.85
15	.79
20	.72

It is apparent, therefore, that the absorption of light by the water exerts an important influence on the visibility of the wire. The absorption of light by the particles of suspended matter at different depths is an even more important factor, but its amount is unknown Furthermore, the opaque particles act as a screen to shut out the object in view, and the distance of these particles from the eye must be taken into account. The optical phenomena involved are complicated, and it is unnecessary to analyze their relative importance. It is sufficient to determine at what depths the wire becomes invisible in waters of definite turbidity with different degrees of dilution, and from these to formulate a law for practical application.

Distilled water rendered turbid by the addition of 1,000 parts per million of finely divided silica was put into a jar, and the depth of the disappearing wire observed. It was then diluted with distilled water to various degrees, and a series of similar observations made. The results of these observations are shown in Figure 1.

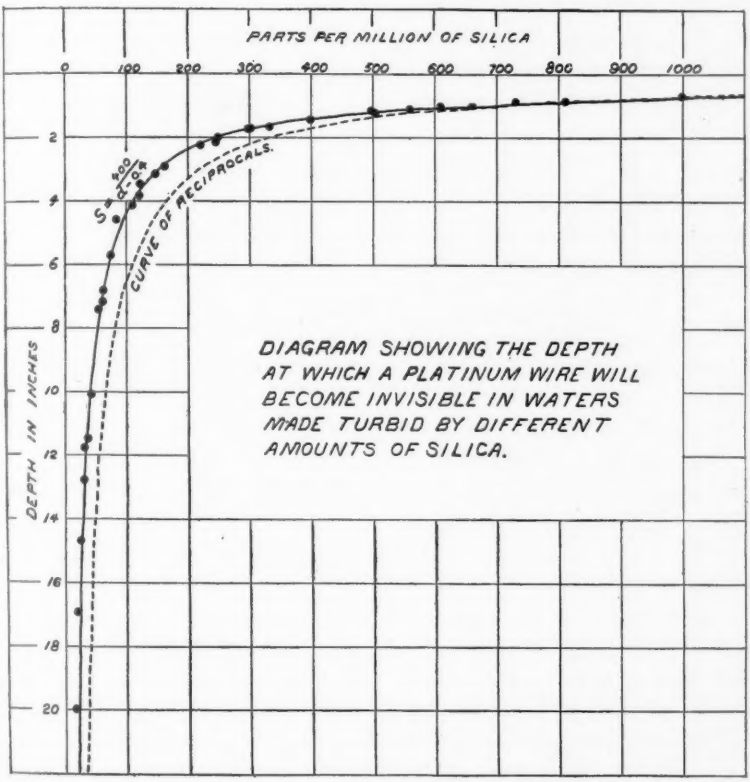

FIG. 1.

It was found that when the water contained 666 parts of silica per million, the wire disappeared at a depth of one inch. This turbidity therefore corresponds to unity of the present method of stating results by the use of the wire. Starting from this point, the curve of the reciprocal scale is shown by the dotted line. According to this curve the wire should have disappeared at two inches when the water con-

tained 333 parts of silica, at three inches when it contained 222 parts, and so on. The diagram shows, however, that the depths of the disappearing wire did not follow the reciprocal curve, but did follow a somewhat similar curve. Within the limits of practical observation this curve was found to have the following formula:

$$S = \frac{400}{d - 0.4}$$

where S represents the number of parts per million of the silica standard, and d represents the depth of the wire in inches,
or

$$S = \frac{1.016}{d' - 1.016}$$

where d' represents the depth of the wire in centimetres,
or

$$S = \frac{400\,t}{1 - 0.4\,t}$$

where t represents the turbidity expressed in terms of the reciprocal scale.

This curve is shown on the diagram by the full line.

Observations were then made with other substances than silica, to see if this formula could be generally applied. Natural turbid waters from various sources were diluted with distilled water and the depth of the disappearing wire ascertained. Some of these results are shown in Figure 2.

As in Figure 1, the dotted line represents the curve of reciprocals, and the full line the curve obtained by plotting the above formula. In Figure 2, however, the abscissæ represent not weights of silica, but a uniform scale of turbidity, where unity is the turbidity that causes the wire to disappear at the depth of one inch. The black spots represent the observations obtained by the authors using material that was obtained from the experimental filters at Pittsburg,[1] Pa., to produce the turbidity. It will be seen that they follow the curve very closely. The circles represent observations obtained by Parmelee and Ellms on the water of the Ohio River. These also follow the general curve. Observations with natural waters and with waters rendered artificially turbid with kaolin gave similar results, while waters ren-

[1] This material was kindly furnished by Mr. Wm. R. Copeland, Bacteriologist-in-charge.

dered turbid with colored substances, such as coal-dust, lamp-black, iron oxide, etc., gave but slightly different results. In no case did the observations follow the curve of reciprocals, and in every case the curve was similar to that obtained for silica.

It is apparent, therefore, that the above formula may be given general application within the limits of the ordinary observations of

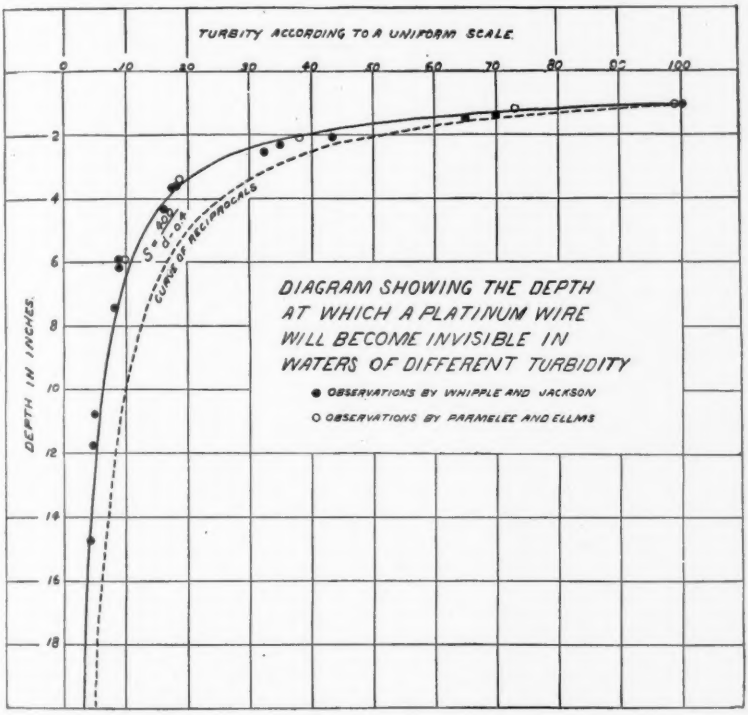

FIG. 2.

turbidity with the wire method. By its use turbidities obtained by the wire method may be expressed in terms of a uniform scale, a decided advantage over the reciprocal scale.

This position is further strengthened by a comparison of the turbidity readings with the amounts of suspended solids. It has been found that the ratio between suspended solids and turbidity expressed by reciprocals of the depth of the disappearing wire is far from constant, but that the ratio between suspended solids and turbidity

calculated to silica from the wire readings is nearly a constant for samples of water from any particular locality. The following observations of suspended solids and turbidity by the wire method, obtained by Parmelee and Ellms for the Ohio River, illustrate this fact.

Weight of suspended solids. (Parts per million.)	Turbidity by wire method. (Reciprocal scale.)	Turbidity reduced to silica standard.	Weight divided by turbidity, according to reciprocal scale.	Weight divided by turbidity in terms of silica standard.
33	0.17	75	195	.44
62	0.30	136	198	.45
126	0.49	244	252	.51
248	0.86	527	275	.47
342	1.02	690	335	.51
453	1.14	833	344	.54
528	1.43	1,333	370	.40
				Average, .47

Hazen, in his Filtration of Public Water Supplies, gives the following equivalents of turbidity readings in weight of suspended matter for river waters with particles of average size. If these turbidities are reduced to silica by the formula, the ratio between turbidity and suspended matter becomes practically a constant when the turbidity by the wire method is less than 1.00.

Turbidity by wire method. (Reciprocal scale.)	Turbidity reduced to silica standard.	Weight of suspended solids. (Parts per million.)	Weight divided by turbidity according to reciprocal scale.	Weight divided by turbidity according to silica standard.
0.05	21	13	260	.62
0.10	42	26	260	.62
0.20	88	55	275	.62
0.30	136	85	283	.62
0.40	189	116	290	.61
0.50	249	150	300	.60
1.00	666	360	360	.54
				Average, .61

The following table will be found convenient for transforming turbidities obtained by the use of the wire at the distance of normal vision, and expressed according to the reciprocal scale into parts per million of silica.

TABLE FOR TRANSFORMING TURBIDITIES OBTAINED BY USING THE WIRE METHOD WITH THE RECIPROCAL SCALE INTO TURBIDITIES EXPRESSED IN PARTS PER MILLION OF THE SILICA STANDARD.

Wire reading.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	Parts of Silica Per Million.									
.00	00	4	8	12	16	21	25	29	33	37
.10	42	46	50	54	58	63	68	73	78	83
.20	88	92	96	101	106	111	116	121	126	131
.30	136	141	146	153	158	163	168	173	178	183
.40	189	195	201	207	213	219	225	231	237	243
.50	249	256	262	268	275	281	287	295	302	309
.60	316	323	329	336	345	351	358	366	373	381
.70	389	397	404	412	421	429	437	445	453	460
.80	470	478	487	497	506	515	524	534	543	552
.90	562	572	582	592	602	612	623	635	645	656
1.00	666	...	...	...	...	...	...	...	...	...

Wire reading.	.00	.10	.20	.30	.40	.50	.60	.70	.80	.90
	Parts of Silica Per Million.									
1.00	666	786	923	1,084	1,273	1,407	1,777	2,127	2,564	3,174
2.00	4,000	...	...	....	....	....	....	....	....	....

It is preferable, however, to have the turbidity rod graduated in terms of silica as well as in reciprocals. Such a graduated rod is shown in Figure 3. For the purpose of graduating the rod, or for transforming turbidities expressed in depths of the wire, the following table will be found useful.

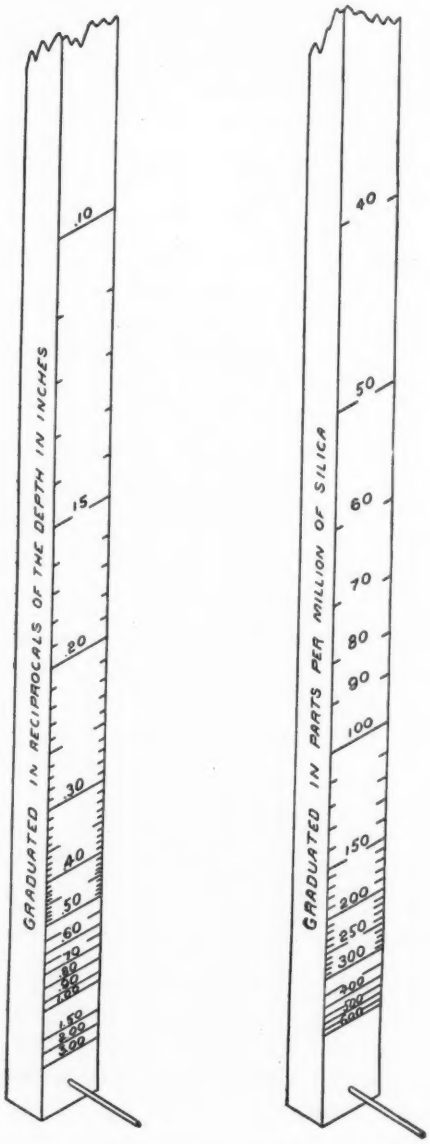

FIG. 3. — TURBIDITY ROD.

TABLE SHOWING THE DEPTH OF WIRE IN INCHES AND CENTIMETERS CORRESPONDING TO TURBIDITIES EXPRESSED IN TERMS OF THE SILICA STANDARD.

Silica.	Depth of wire.		Silica.	Depth of wire.		Silica.	Depth of wire.	
	Inches.	Centimeters.		Inches.	Centimeters.		Inches.	Centimeters.
0	....	....	65	6.54	16.5	240	2.06	5.2
1	400.40	1017.0	70	6.09	15.5	250	2.00	5.1
2	200.40	509.0	75	5.73	14.5	260	1.93	4.9
3	133.73	339.5	80	5.40	13.7	270	1.88	4.8
4	100.40	264.2	85	5.08	13.0	280	1.83	4.7
5	80.40	223.4	90	4.84	12.2	290	1.78	4.6
6	67.06	170.3	95	4.60	11.7	300	1.73	4.5
7	57.58	146 3	100	4.40	11.2	400	1.40	3.5
8	50.40	138 2	110	4.04	10.2	450	1.29	3.3
9	44.84	113.8	120	3.73	9.4	500	1.20	3.1
10	40.40	111 8	130	3.48	9.0	600	1.06	2.7
15	27.00	68.6	140	3.25	8 5	666	1.00	2.5
20	20.40	61.0	150	3.06	7.9	700	96	2.4
25	16.40	41.7	160	2.90	7.3	800	90	2.3
30	13.73	34.8	170	2.75	7.0	900	84	2.1
35	11 83	30 0	180	2.62	6.6	1,000	80	2.0
40	10.40	26.4	190	2.50	6 3	....	....	...
45	9.28	23 6	200	2.40	6.1	....	....	...
50	8.40	21.3	210	2 30	5.8	....	....	...
55	7.67	19.5	220	2.23	5.6	....	....	...
60	7.07	17.9	230	2.13	5.3	....	....	...

The Diaphanometer Method.

Parmelee and Ellms, in their use of the diaphanometer, found that the ratio between the suspended solids and the turbidity expressed in terms of the reciprocal scale was not a constant, but increased with the turbidity, as shown in the following table :

Weight of suspended solids. (Parts per million.)	Turbidity by diaphanometer, using reciprocal scale.	Weight divided by turbidity.
33	.07	465
62	.13	484
126	.21	583
248	.38	657
342	.46	745
453	.55	820
528	.62	855

Accordingly, they adopted the following formula for transforming turbidities into weights of suspended matter:

Weight in parts per million = 600 (Turbidity — 0.01),

where the turbidity equals the reciprocal of the depth in inches of the water in the diaphanometer tube. On account of the nature of suspended matter in the water used in their work this formula is necessarily only of local application.

Through the courtesy of Mr. George W. Fuller the authors have had the privilege of experimenting with the diaphanometer used by Parmelee and Ellms at Cincinnati. Turbidity observations have been made upon waters rendered artificially turbid by the addition of silica standard in various amounts. The results are shown in Figure 4. It was found that, with a turbidity produced by 1,000 parts of silica per million, the cross of light in the diaphanometer tube disappeared from view at a depth of 1.96 inches. With this as a starting point, the reciprocal scale would follow the curve shown by the dotted line. The observations, however, did not follow this curve. The curve of observations was similar to that obtained with the wire method, but the variations from the reciprocal curve were somewhat greater than was the case with the wire method. The curve of observations was found to have the following formula:

$$S = \frac{958}{d - 1}$$

where S represents the number of parts of silica per million and d equals the depth of the liquid in the tube in inches,

or

$$S = \frac{2{,}433}{d' - 2.54}$$

where d' equals the depth in centimetres,
or

$$S = \frac{958\,t}{1 - t}$$

where t represents the turbidity according to the reciprocal scale.

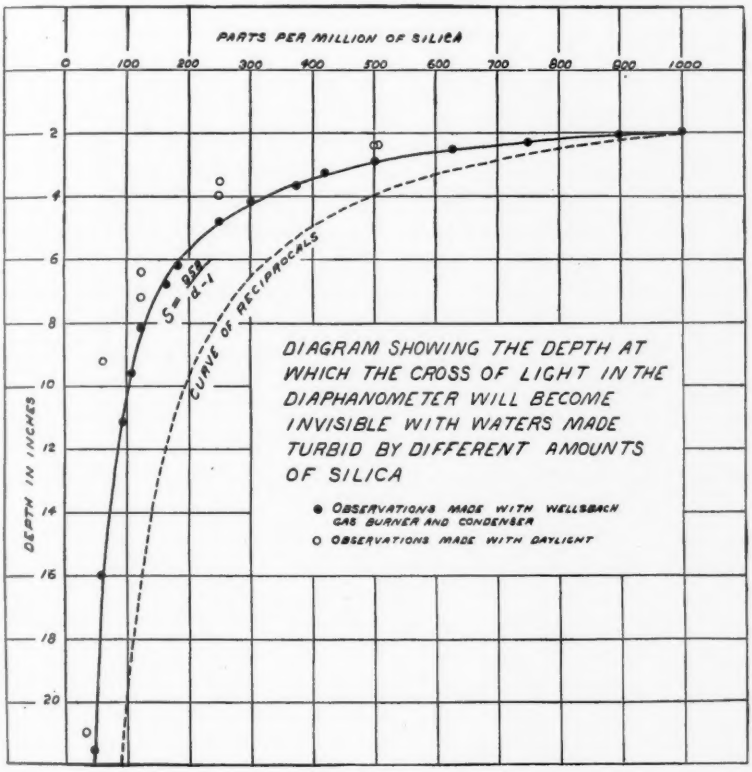

FIG. 4.

This formula is shown on the diagram by the full line, and the observations obtained by using a Wellsbach burner are indicated by the black spots. The circles represent the results obtained by using daylight reflected from a white surface instead of gaslight. They

show that the observations vary greatly with the intensity of the light, a fact naturally to be expected. It is evident, therefore, that for accurate work the light must be under definite control, and that for any given intensity of light a corresponding formula must be used. In other words, every diaphanometer must be calibrated for the exact condition under which it is to be used. When so calibrated the results may be expressed in terms of the silica standard according to a uniform scale.

Comparison with Standards.

The direct use of silica standards of comparison is limited to waters having turbidities of less than 100 parts of silica per million. For more turbid waters it is necessary to dilute with clear water before reading. With very turbid waters the multiplied error of reading becomes appreciable, yet it probably does not exceed the errors of the other methods for waters of the same turbidity. If a series of standards is prepared in bottles and tubes differing by 5 parts per million between 0 and 30, it is possible to match turbidities within about 2 parts per million; above 30, with standards differing by 10 parts, it is possible to match within 2 to 5 parts, the more turbid waters being more difficult to match.

Comparison of Turbidity Readings by the Various Methods.

There remains to be considered the agreement between turbidity readings obtained by the various methods. Theoretically the readings obtained by the wire method and the diaphanometer should, when reduced to terms of silica by the formulæ given, agree with readings obtained by direct comparison with silica standards. As all of the methods, however, are subject to error, some differences in the readings are to be expected. The following table shows the results of turbidity observations made by the three methods, upon waters from various parts of the country. These contained clay which in some instances was slightly discolored by iron oxide and organic matter:

TURBIDITY.

(EXPRESSED IN PARTS PER MILLION OF SILICA.)

Sample number.	By wire method.	By diaphanometer.	By comparison with silica standards in tubes.
1.	250	239	220
2.	150	162	140
3.	75	79	77
4.	480	490	450
5.	58	55	55
6.	720	740	680
7.	1,020	980	950
8.	740	780	730

From such comparative observations, only a few of which are given in the table, it has been found that the average deviation from the mean of the three readings is less than 5 per cent., a result which may be considered as quite satisfactory. When waters are rendered turbid by particles which have a marked color of their own, the comparison between the three methods fails, as described beyond.

The ratio between the turbidity expressed in silica and the weight of the suspended solids varies with the size of the particles present. This is shown by the following table:

	Ratio between the weight of suspended matter in parts per million, and turbidity according to silica standard.
River waters with coarsest sediments, (from Hazen) . .	1.09
River waters with average sediments, (from Hazen) . .	.61
River waters with finest sediments, (from Hazen) . . .	.39
Ohio River water, (from Parmelee and Ellms)	.47
Ohio River water after sedimentation, (from Parmelee and Ellms)	.28
Hudson River at Albany	.72
Passaic River at Little Falls	.65
Delaware River	.62
Lake, Prospect Park, Brooklyn	.71
Allegheny River at Pittsburg	.48

When, however, comparisons between turbidity and weight of suspended matter are made for any particular locality, the ratio is surprisingly constant, as already pointed out. It is possible that some universal method of transforming turbidity readings to weights of suspended matter might be devised, based upon turbidity readings made before and after various periods of subsidence under definite conditions.

MEASUREMENT OF TURBIDITY PRODUCED BY COLORED PARTICLES.

The effect of the color of water upon turbidity observations with the wire method is slight in very turbid waters, but becomes apparent when the depth of wire increases. One thousand parts of silica per million were added to distilled water, and to a water that had a color of 1.04 on the Platinum Scale. These were diluted to various degrees and the turbidities observed. The results, reduced to silica by the formula given above, were as follows:

	CALCULATED TURBIDITY EXPRESSED IN PARTS PER MILLION OF SILICA.	
	Distilled water.	Colored water.
Original	1,000	1,000
Diluted $\frac{1}{2}$	500	500
Diluted $\frac{1}{4}$	250	220
Diluted $\frac{1}{8}$	125	112
Diluted $\frac{1}{16}$	63	55
Diluted $\frac{1}{32}$	42	36

When the disc method is used in comparatively clear waters the effect of color is considerable, as shown by the following observations:

Color of the Water. (Platinum Scale.)	Depth of Disappearing Disc in inches.
.16	174
.56	130
.69	110

Most turbid waters met with in nature have a dissolved color insufficient to seriously interfere with the results of the turbidity observations. Some waters, however, are rendered turbid by particles which are themselves colored. Certain streams in Pennsylvania, for example, are black from the presence of coal-dust; others are red from the presence of large amounts of clay colored by oxide of iron; while waters receiving discharges from dye-houses and other forms of manufacturing waste may be variously colored. It has been found that, because of the absorption of light by these various substances, the optical methods of determining turbidity fail to give true results.

For example, a water that had a marked red color gave a turbidity of 420 when compared with the silica standards in the tubes, while by the wire method the turbidity was 660, and by the diaphanometer, 684. A water that contained lampblack gave 250 by direct comparison and 470 by the wire method, while another sample gave 500 and 1,300 respectively.

In order to see whether the direct method of comparison was correct when applied to turbidities produced by particles different in color, lampblack was ground until the particles were the same size as those of the silica standard, as nearly as could be ascertained by microscopical measurement. Two series of turbid waters were prepared, one with black particles and the other with approximately equal numbers of white particles. Comparison of the two series gave the following results:

	Parts Per Million.								
Lampblack	20	30	40	50	60	70	80	90	100
Silica	18	25	32	43	52	66	70	78	88
Ratio	.90	.83	.80	.86	.84	.87	.87	.85	.88
Average ratio, 0.87									

The turbidities thus produced agreed therefore within 13 per cent. Similar comparisons made with the wire method gave the following results:

	Parts Per Million.		
Lampblack	63	125	250
Wire method reduced to silica . . .	88	207	470
Ratio	1.42	1.65	1.44

These results differed by about 50 per cent. With deeper turbidities the ratio was still further increased.

Conclusions.

From the preceding investigations it appears that the use of the silica standard permits the turbidity of water to be accurately expressed in terms of a uniform scale; that with waters of ordinary turbidity, results obtained by the use of the wire and the diaphanometer may be reduced to the silica standard with a considerable degree of exactness; that with waters rendered turbid by colored particles the optical methods fail to give correct results; that the ratio between turbidity in terms of silica and weight of suspended matter varies with the size of the particles, but is nearly constant for any particular locality.

Remark. — After experimenting with various forms of diatomaceous earth in the preparation of silica standards, the authors have found that, while any such earth may be used if the directions given in their previous article are followed, the most satisfactory earth for the purpose is that from a deposit at Herkimer, New York. This deposit is quite free from sponge spicules and from foreign matter, rendering the preparation of the turbidity standard a simple operation. No washing with acid is necessary, and after a short ignition and a thorough grinding, the material is ready for use. This diatomaceous earth may be obtained from George W. Searles, Herkimer, New York.

The authors have had recently the opportunity to compare the stock mixtures of silica turbidity standards made by several different observers, and it has been gratifying to find that in almost every case the agreement has been within the limits of reading. In no case did one standard differ from the others by more than 3 per cent. During the process of grinding the particles of silica show a slight tendency to mat together. These mats should be removed before weighing by sifting the material through a 200-mesh sieve.